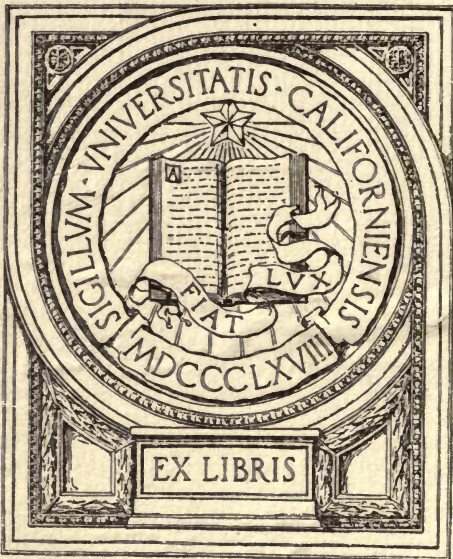


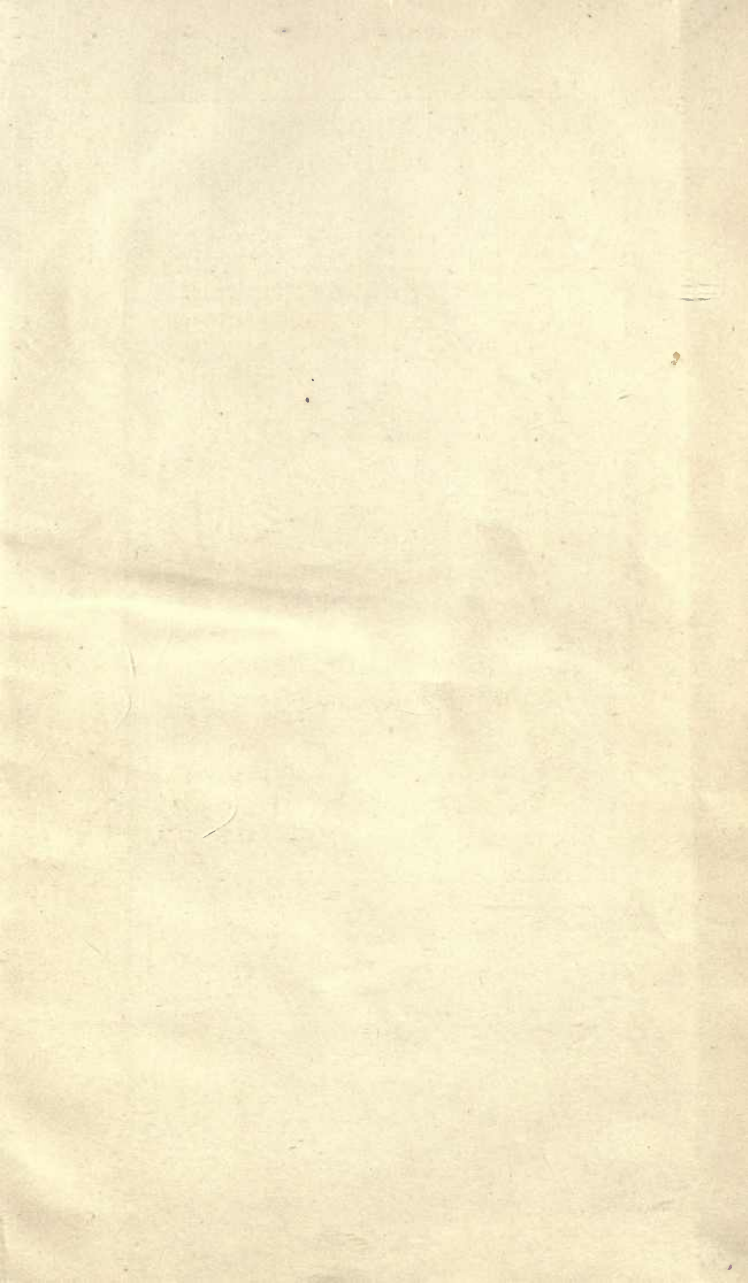


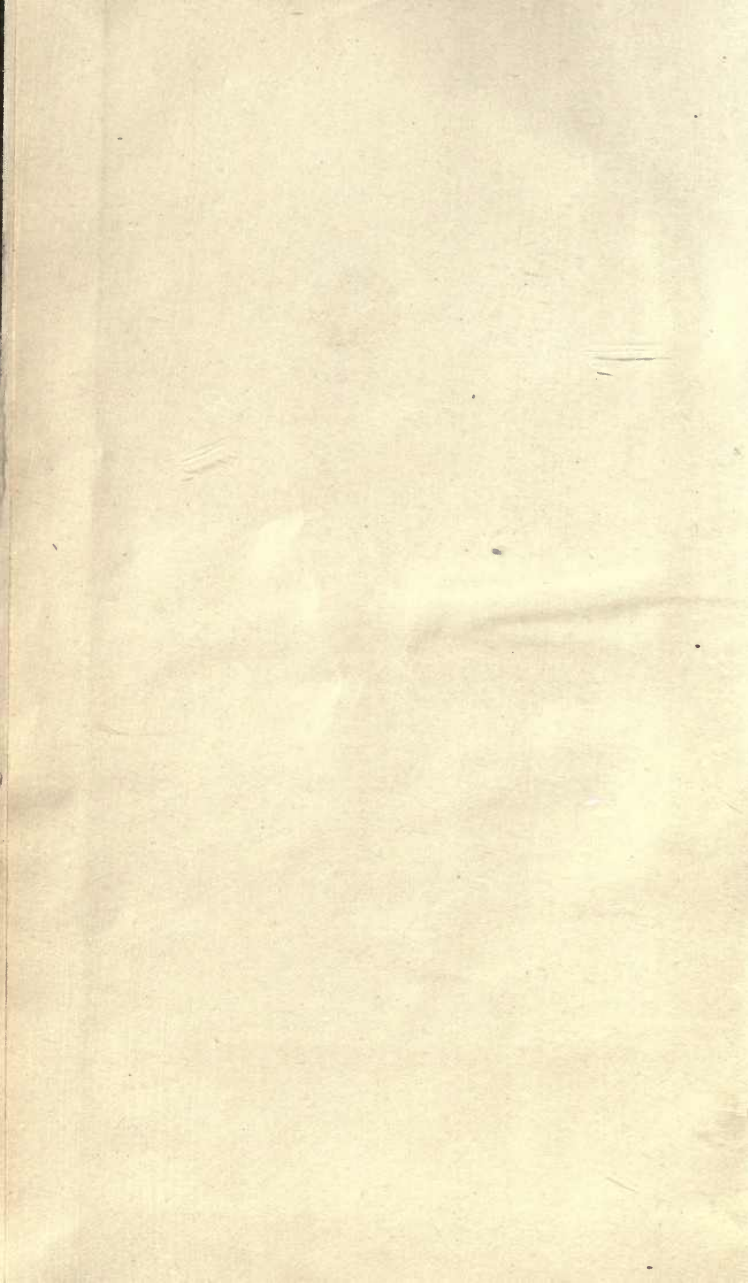
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INTRODUCTORY TEXT-BOOK

OF

GEOLOGY

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PAGE AND LAPWORTH

INTRODUCTORY TEXT-BOOK

GEOLOGY

# INTRODUCTORY TEXT-BOOK

OF

# GEOLOGY

BY

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PROFESSOR OF GEOLOGY IN THE DURHAM UNIVERSITY COLLEGE OF  
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TWELFTH AND ENLARGED EDITION



WILLIAM BLACKWOOD AND SONS  
EDINBURGH AND LONDON

MDCCCLXXXVIII

1888

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INTRODUCTORY TEXT-BOOK

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GEOLOGY

"The study of the structure of the Earth must tend to enlarge the mind of man, in seeing what is past, and foreseeing what must come to pass in the economy of nature; and here is a subject in which we find an extensive field for investigation, and for pleasant satisfaction."—HUTTON's *Theory of the Earth*, 1795.

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## PREFACE.

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THE object of this little Treatise is to furnish an elementary outline of the science of Geology. In its preparation the utmost care has been taken to present a simple but accurate view of the subject, to lead the learner from things familiar to facts less obvious, and from a knowledge of facts to the consideration of the laws by which they are governed. By adopting such a method, Geology, instead of being a dry accumulation of facts, and its study a mere task of memory, becomes one of the most attractive departments of Natural Science, and affords one of the finest fields for the exercise of the observing and reflective faculties. The treatise, though initiatory, is arranged on a strictly scientific basis, the Author being convinced that the student's progress is best promoted by commencing at once with the technical treatment of his subject, and making him feel that he is step by step acquiring the power to master for himself the higher and more difficult deductions. Such a course may require closer attention, and cost him a little more labour at the outset; but it will be found, as he advances, to be the more pleasant as well as the more profitable mode of procedure. Whatever may be the defects of this manual, the Author has endeavoured to write as a geologist—to afford the pupil an accurate outline

of the science, should he stop short at this stage of his progress, and to present him, should he wish to prosecute the study, with a gradual introduction to a more advanced and comprehensive text-book.

EDINBURGH, *August 1854.*

SECOND EDITION *published August 1855.*

THIRD " " *April 1857.*

FOURTH " " *April 1860.*

FIFTH " " *November 1861.*

SIXTH " " *November 1864.*

SEVENTH " " *June 1867.*

EIGHTH " " *February 1869.*

NINTH " " *August 1871.*

TENTH " " *April 1873.*

ELEVENTH " " *October 1877.*

## TWELFTH EDITION.

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IN preparing the present edition of this work, I have been desirous, while retaining the general sequence and mode of treatment of the subject adopted in former editions, to make the book, as far as it goes, a brief epitome of our present knowledge of the science of Geology, as viewed from the most recent standpoint. I have also naturally been anxious that the book should maintain its reputation as affording a general introduction to the science,—suitable, on the one hand, for beginners and for the higher classes in schools; and on the other, available for the purposes of systematic students of the elementary branches of the subject in evening classes and colleges. In each section, therefore, I have endeavoured to give, with simplicity and clearness, but with as much fulness as is compatible with the size of the work, an explanation, description, and illustration of the more important facts and principles upon which the science is based. But the progress of Geology has been so great of late years, that in order to bring all the departments up to date, I have found it necessary to recast or rewrite almost the whole of the work, with the exception of the introductory and concluding chapters.

Those teachers who have been in the habit of using the

book will find that the Physical half of the book has been extended by the addition of fresh chapters on Dynamical Geology, and on the Volcanic and Metamorphic rocks, embodying the recent discoveries in these departments. In Historical Geology the earlier chapters have been rewritten, and the others brought up to date; special stress has been laid upon the geographical and biological aspects of each of the geological systems; and a special chapter has been devoted to the Glacial period.

For the benefit of those who use this work in schools, a brief recapitulation is appended to each chapter; and for the use of systematic students of the science, detailed classifications of rocks and rock-formations are inserted in smaller type.

In order to include the new matter, the work has been enlarged by the addition of seventy-five pages of letterpress. About fifty fresh illustrations have also been added. Some of these are new. For his kindly permission to use the majority I have to thank my friend, Prof. H. Alleyne Nicholson, M.A., of Aberdeen University.

CHAS. LAPWORTH.

MASON COLLEGE, BIRMINGHAM,  
*February 1888.*

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# G E O L O G Y.

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## CHAPTER I.

### INTRODUCTORY OUTLINE.

#### OBJECTS AND SCOPE OF THE SCIENCE.

1. GEOLOGY (from two Greek words—*ge*, the earth, and *logos*, a discourse or reasoning) embraces, in its widest sense, all that can be known of the constitution and history of our globe. Its object is to examine the various materials of which the accessible parts of our planet are composed, to describe their appearance and relative positions, to investigate their nature and modes of formation, to note the changes they have undergone and are still undergoing, and generally to discover the laws which determine their characters and arrangements.

2. As a department of natural science, Geology confines itself more especially to a consideration of the *mineral or rocky constituents of the earth*, and leaves its present surface-configuration to Geography, its vegetable life to Botany, its animal life to Zoology, and the elementary constitution of all bodies to the science of Chemistry. As geologists are unable to penetrate beyond a few thousand feet into the solid substance of the globe, their labours are necessarily confined to its accessible exterior. By the scientists of former times it was believed that the interior or "*nucleus*" of the globe was kept in a molten state by excessive heat, and that this liquid portion was surrounded by the solid outer shell or "*crust*." Adopting this terminology, geologists speak of the "*crust of the globe*," meaning thereby that outer portion which is accessible to human investigation, and about whose nature and history they can reason with certainty.

3. The materials composing this crust are *rocks* and mineral matter of various kinds—granite, basalt, slate, sandstone, marble, coal, chalk, clay, and sand—some hard and compact, others soft and incoherent. No matter what may be their degree of consolidation, they are all without exception known to the geologist as “*rocks*.” These rocks do not occur scattered indiscriminately, nor, when found, do they always appear in the same relative position. Granite, for example, may exist in one district, marble in another, coal in a third, and chalk in a fourth. Some occur in regular layers (*a*) or courses, termed *strata* (from the Latin word *stratum*, strewn or spread out), and are known as *stratified rocks*. Others rise up in irregular masses (*m*), having no lines nor layers of stratification, and are consequently designated *unstratified rocks*. Some lie flat, others slope at high angles; some are bent into arch-like ridges, others into basin-shaped hollows; some occur in



Fig. 1.—*Stratified and Unstratified Rocks.*

alternating sheets (*a*), while others burst through these layers, interrupt their continuity, and rise over them in mountain-masses (*m*). It is evident that rocks differing so widely in composition and structure must have been formed under different circumstances, and by different causes. It becomes the task of the geologist to discover those causes, and to indicate the conditions of the regions in which, and of the periods when, such rocks were produced.

4. When we sink a well, for example, and dig through clays, sands, and gravels, and find them succeeding each other in layers, we are instantly reminded of the *operations of water*, for it is only by the agency of water that accumulations of clay, sand, and gravel are formed at the present day. Not only are we thus led to inquire as to the origin of the materials through which we dig, but we very naturally seek next to discover whether they were originally deposited in river-courses, in lakes, in estuaries, or along the sea-shore. In our investigation, again, we may perhaps detect shells, bones, and fragments of plants embedded in the clays and sands; and thus we

have a further clue to the mode of origin of the strata through which we pass, according as the shells and bones are the remains of animals that lived in the fresh-water lakes and rivers, or inhabited the waters of the ocean. Again, in making a railway-cutting, excavating a tunnel, or sinking a coal-pit, we may pass through many different successions of strata—such as clay, sandstone, coal, ironstone, limestone, and the like; and in such cases we almost invariably find that each succession of strata contains the remains or impressions of different plants and animals. Such differences can only be accounted for by supposing each set of strata to have been formed under different arrangements of sea and land, as well as under different conditions of climate; just as at the present day the lakes, estuaries, and seas of different countries are characterised by their own special accumulations, and by the embedded remains of the plants and animals peculiar to these regions.

5. In making such investigations, the geologist is guided by his knowledge of *what is now taking place on the surface of the globe*—ascribing the origin of such rocks as resemble recent mineral accumulations, formed by existing agencies, to the same agencies acting similarly in the far distant past. Thus, in the present day, we see *rivers* carrying down sand and mud and gravel, and depositing them in layers, either in lakes, in estuaries, or along the shores and bottom of the ~~ocean~~. By this process many lakes and estuaries have, within a comparatively recent period, been filled up and converted into dry land—the layers of sand and mud gradually consolidating and hardening into rocky strata. We see also the tides and *waves* wasting away the sea-cliffs in more exposed districts, and accumulating expanses of sand and salt-marsh in sheltered localities. By these agencies thousands of acres of land have been washed away by the sea, even within the memory of man; while by the same means new tracts have been formed in districts formerly covered by the tides and waves. Further, we learn that, during earthquake convulsions, and, on a far grander scale, in those *slow movements of elevation and depression* the effects of which are only discernible after the lapse of ages, large districts of country have sunk beneath the waters of the ocean; while in other regions the sea-bed has been elevated into dry land. And, finally, we are all familiar with the fact that, in the neighbourhood of the present shore-line of the continents, *volcanic action* is visibly affecting the surface of the globe—converting level tracts into mountain-ridges, throwing up new

islands from the sea, and casting forth molten lava and other materials, which in time become hard and crystalline rock-masses, like the greenstones and basalts of our older hills.

6. As these forces are at present modifying the surface of the globe, and changing the relative positions of sea and land, so in all time past they must have exerted a similar influence. The exterior of this world of ours is, and has ever been, subject to incessant *waste* and *reconstruction*—here wasted and worn down by frosts, rains, rivers, waves, winds, and tides, and there built up again by the deposition of the water-borne materials, by the growth of plants and animals, and by the accumulation of volcanic ejections. Not a foot of the land we now inhabit but has probably been repeatedly under the sea, and, it may be, the present bed of the ocean has formed repeatedly the habitable dry land. No matter how far inland, or at what elevation above the sea, we now find accumulations of sand and gravel—no matter at what depth we discover strata of sandstone or limestone—we feel confident, from their composition and arrangement, that they must have been formed under water, and brought together by the operations of water, just as layers of sand and gravel and mud are accumulated or deposited at the present day. And as crust movements, earthquakes, and volcanoes break up, elevate, and derange the present dry land—here sinking one portion, there tilting up another, and everywhere producing rents and fissures—so, we rest assured, must the fractures, derangements, and upheavals among the strata of the rocky crust have been brought about by the operation of similar agents in remote and distant epochs.

7. By the study of existing operations the geologist obtains a clue to the history of the globe; and his task is rendered much more interesting, and his results more exact and reliable, by an examination of the plants and animals found embedded in the various strata. At present, the hard coverings of shell-fish, the skeletons of fishes, and other sea animals are buried in the mud or silt of lakes and estuaries; rivers carry down the remains of land animals, the trunks of trees and other vegetable drift; and earthquakes submerge plains and islands, with all their vegetable and animal inhabitants. These remains become enveloped in the layers of mud and sand and gravel formed by the waters, and in process of time many become *petrified* (Lat. *petra*, a stone, and *fio*, I become); that is, become converted into stony matter like the shells found in the rocky strata. When they are exhumed by the geologist, they give evidence of the physical conditions under which they

lived—whether aquatic or terrestrial, tropical, temperate, or arctic. It is perfectly clear that, as at present, so in all former time, the remains of plants and animals must have been similarly preserved; and as one tribe of plants is peculiar to the dry plain, and another to the swampy morass—as one family belongs to a temperate, and another to a tropical region—so, from the character of the plants embedded in the rocks are we enabled to arrive at some knowledge of the conditions under which they flourished. Again, each tribe of animals has its locality assigned it by peculiarities of food, climate, and the like; each family has its own peculiar structure for running, flying, swimming, plant-eating or flesh-eating, as the case may be; and by comparing *fossil* remains of animals (*fossil*, from Lat. *fossus*, dug up—applied to all remains of plants and animals embedded in the rocky crust) with existing races, we are enabled to determine many of the past climatic conditions of the world with considerable certainty. Of course, the more remote the period, or, in other words, the older and deeper the rocks, the more difficult will be this determination; just as from a study of antiquarian objects it is easier to arrive at a knowledge of the manners and customs of those who immediately preceded our own times, than of those whose monuments are older than all written record or oral tradition.

8. By examining, noting and comparing, as indicated in the preceding paragraphs, the geologist finds that *the strata composing the earth's crust can be arranged in groups or series*; that one special set or series is always succeeded by, or underlies another set; and that each series contains the remains of plants and animals not to be found in any other series. Having ascertained the existence of such a sequence among the rocky strata, his next task is to determine that sequence in point of time—that is, to determine the older from the newer series of strata; to ascertain, if possible, the nature of the plants and animals whose remains are embedded in each set; and lastly, to discover the geographical range or horizontal extent of the successive series. These series he calls *formations*, as having each been formed or deposited in lakes, estuaries, or seas, during different arrangements of sea and land, and under influences of climate or other external conditions. It is by a knowledge of these formations, and by a careful digest, comparison, and rigid sequential classification of the information they afford him, that the geologist is enabled to arrive at a broad outline of the history of the globe—imperfect, it is true, but still sufficient to show the numer-

ous changes its surface has undergone, and the varied and wonderful races of plants and animals by which it has been successively inhabited. Thus not only does geology (*a*) investigate the origin, composition, structure, and arrangements of the rock-masses that constitute the earth's crust; but it also endeavours (*b*) to map out the various mutations of sea and land, from the present moment to the earliest time of which we have any traces in the rocky strata, to restore the forms of extinct plants and animals, to indicate their habits, the climate and conditions under which they grew and lived, and even their connection with existing races. To the former part of our science we apply the term *Physical Geology*, and to the latter the title of *Historical Geology*.

#### THEORETICAL AND PRACTICAL BEARINGS OF THE SCIENCE.

9. Such are the objects and scope of Geology, regarded solely from a *theoretical* point of view. This aspect of the science is one of comparatively recent development, but one of high and enduring interest. The problems Theoretical Geology proposes to solve are among the most attractive that can engage the ingenuity of man—leading him from his own position and connection with the present aspects of this planet, back through all its former conditions, as far as science is able to penetrate into the dim remoteness of the distant past. As a legitimate cultivator of natural science, the geologist bases his deductions on definite and well-observed facts; collects, arranges, and compares, with honest and scrupulous care; and proceeds from phenomena that are easily understood and taking place around him, to the explanation of those that are remote and less apparent. His object is to unfold the history of our globe as revealed in the composition and arrangement of the rocky crust, with all its embedded remains of past life; and, whether in collecting data among the hills and ravines, by the sea-cliff or in the mine, or in arranging and drawing from these data the warranted conclusions, the earnest student will find Geology at once one of the most healthful and exhilarating, as it is one of the most attractive and expanding, of intellectual pursuits. It requires accurate observation, cautious comparison, and careful deduction at every step; and the powers of observing correctly, of comparing without bias, and of deducing in logical sequence, are among the highest attainments of the human intellect.

10. Nor is the science, in a *practical* point of view, of less importance to man. Deriving, as we do, all our metallic and mineral stores from the crust of the earth, it is of the greatest utility to be able to distinguish correctly between mineral substances, to determine in what positions they occur, to inform the *miner* with certainty where they are to be found, and with what facilities they can be obtained. Again, the *engineer*, in tunnelling through hills, in cutting canals, excavating harbours, sinking wells, bringing in water-supplies, and the like, must, to do his work securely and with certainty, base in a great measure his calculations on the nature of the rocky materials to be passed through—information he can obtain only through the deductions of Geology. The *architect* also, in selecting his material, by attending to the formation and texture of the rock, and observing how it has been affected by the weather in cliffs and ravines, may often avoid the needless expense incurred by the unfortunate selection of a wasting and worthless building-stone; while his knowledge of geological succession will enable him to detect in different localities the material he requires. The *farmer*, in like manner, whose soils are either formed by the disintegration of the subjacent rocks, or are affected by their retentive or absorbent nature, may learn much useful information from the demonstrations of the geologist. The study of *physical geography*, in relation to the migrations and habitats of plants and animals, the acclimatising and cultivation of certain animals and vegetables, and even touching the development and health of man himself, can only attain the character and position of a science, if treated in connection with the fundamental doctrines of Geology. Again, the *artist and landscape-gardener* may reap substantial benefit from a study of the science as bearing on surface-configuration and character of scenery; and though such a knowledge, of itself, will make neither artists nor landscape-gardeners, it will often prevent them from committing unpardonable outrages on the landscapes of nature. Indeed, to all who have to deal with minerals and metals some little knowledge of Geology will be of advantage; while in a country like Britain, whose mechanical, manufacturing, and commercial greatness depends so intimately upon her subterranean treasures, few subjects can be more deserving of enlightened attention.

11. To acquire a knowledge of the science sufficient for the purposes indicated in the preceding paragraph, is not a very difficult task. The objects of geological research are scattered

everywhere around us. Not a quarry we visit by the way-side, not a railway-cutting through which we are carried, not a mountain-glen up which we climb, nor a sea-cliff under which we wander, but furnishes, when duly observed, important lessons in geology. A hammer to detach specimens and a bag to carry them in, a sketch-book to note unusual appearances, an observing eye, and a pair of willing limbs, are nearly all the young student requires for the field ; and by inspection and comparison of the rocks and fossils in some museum, and by the diligent use of his text-book, he will very shortly be able to proceed in the science as a practical observer. Let him note every new and strange appearance, handle and preserve every specimen with which he is not familiar—throwing nothing aside until he has become acquainted with its nature ; and then, besides obtaining additional knowledge and facilitating his progress, he will shortly acquire the invaluable power of prompt and accurate discrimination.

#### RECAPITULATION.

12. In the preceding paragraphs we have endeavoured to explain that the object of Geology is to investigate the structure of the earth, in so far as that structure is accessible to human investigation. Combining all we know of this rocky structure, from the top of the highest mountain to the bottom of the deepest mine, we find that the portion open to our investigation forms but an insignificant film of the four thousand miles which lie between the surface and centre of the globe. This film or outer portion is spoken of as the “crust” of the globe, in contradistinction to the “interior” portions, of which we can know nothing by direct observation. Thin as this crust may appear, it is nevertheless the theatre of extensive, diversified, and ceaseless changes. Every change arising from the violence of the earthquake and volcano, every modification resulting from the waters that cover or course over its surface, every operation dependent on atmospheric agency, as well as all that appertains to the development of vegetable and animal life, is performed on or within this shell. The rocks that are wasted and washed from one district are but reconstructed as new formations in another ; and every formation contains within it, more or less perfectly, some evidence of the physical and vital conditions that existed during its accumulation.

13. The earth crust is thus at once the theatre of all geological change, and the index to all geological history—its strata being like the leaves of an ancient record that may certainly be deciphered with care and competent skill. By noting the composition of its rocks, their position and succession, the space over which they spread, and the fossils they contain, the geologist is enabled to indicate the condition and appearance of the world during former epochs—to speculate as to the former distributions of sea and land, the modifications of climate thereby occasioned, and the kinds of vegetables and animals that successively peopled the earth's surface. To arrive at a rational history of the successive phases of the globe is the aim of theoretical geology; to discover and classify its mineral stores—to ascertain their position and determine their abundance, so as to make them available for the industrial purposes of life—is the task of the practical geologist. Combining its economic with its speculative bearings, Geology becomes a science of high and enduring interest, deserving the study of every cultivated mind, and the encouragement of every enlightened government.

14. A study so vast and varied necessarily resolves itself into several departments. Primarily we may regard the science of geology as separable into two main divisions. PHYSICAL GEOLOGY, which treats of the origin, composition, and arrangement of the *materials* of the earth crust; and HISTORICAL GEOLOGY, which deals with the past *conditions* and aspects of the globe, and of the *life* with which its lands and waters have been successively peopled. Each of these divisions again breaks up into sections. Thus, Physical Geology may be regarded as embracing—

(1.) *Dynamical Geology* (Gr. *dunamis*, power), which treats of the powers or agencies concerned in the formation, elevation, and degradation of rock masses;

(2.) *Petrological Geology* (*petra*, a rock), which deals with the composition and arrangement of rocks, and includes—

(2a.) *Lithological Geology* (*lithos*, a stone), which treats merely of the composition and structure of rocks; and

(2b.) *Structural Geology*, which describes the structure and arrangement of rocks as seen in mass in the earth crust.

To Historical Geology appertain the following divisions:—

(3.) *Palæontology* (Gr. *palaïos*, ancient; *onta*, beings), which deals with the animals and plants found fossil in the rocks.

(4.) *Stratigraphy* or *Descriptive Geology*, proper, which is devoted to a description of the various geological formations, and an account of the past conditions, physical and vital, of the globe.

Finally, it is convenient to allow a supplementary division—**ECONOMIC** or **APPLIED GEOLOGY**, which treats of those substances which can be turned to account in the industrial purposes of life—their nature, abundance, where they occur, how they occur, and with what facilities they can be obtained.

## PART I.—DYNAMICAL GEOLOGY.

### CHAPTER II.

#### CAUSES OPERATING ON THE CRUST OF THE GLOBE AND MODIFYING ITS STRUCTURE AND CONDITIONS.

##### SUB-AERIAL OR EXTERIOR AGENCIES.

15. THE aim of Geology, as stated in the preceding chapter, is to furnish a history of the structure and past conditions of the earth. Had the exterior crust been subject to no modifying causes, the world would have presented the same appearance now as at the time of its creation. The distribution of sea and land would have remained the same: there would have been the same surface-arrangement of hill, and valley, and plain, and the same unvarying aspects of vegetable and animal existence. Under such circumstances, Geology, instead of striving to present a consecutive history of change and progress, would have been limited to a mere description of permanently-enduring appearances. The case, however, is widely different. From the moment the earth began to revolve round the sun and rotate on its own axis, there has been one continuous round of change and progression; and so long as the relations of the solar system endure, such changes will continue to be evolved. From the daily rotation of the earth on its slanting axis and its annual revolution round the sun, arise the alternations of day and night, of summer and winter; and from these alternations arise periodical successions of heat and cold. From heat and cold arise vapours, rains, and rivers, winds, frosts, and glaciers, and the periodical changes in animal and vegetable life; from winds arise waves and currents; from

the attractions of moon and sun arise the tides ; and thus from the earth's planetary relations are evolved all those powers and processes which are ever modifying the earth's crust—here wasting and washing away the old rocks, and there reconstructing them into newer formations. Winds, frosts, and rains ; springs, streams, and rivers ; tides, waves, and currents ; the alternate growth and decay of plants and animals ; and the universal operations of chemical agency,—are all continually tending to separate, to recombine, and to rearrange the materials composing the crust of the earth. Again, as a consequence of the original constitution of our globe, we find that its interior is a vast reservoir of heat, the effects of which are evident in the phenomena of hot springs, of geysers, &c., and more strikingly apparent in the floods of melted rock, and the vast quantities of steam and ashes vomited forth from volcanoes. In the terrible phenomena of the earthquake, as well as in the slow alternate upheaval and depression of great tracts of the earth's surface, we recognise the effects of the same great cause, which must be equally operative below the surface, hardening, altering, and displacing the strata subjected to its action. Thus, we have two distinct groups of geological agencies ever busied in modifying the earth crust—the *Sub-aerial* (Lat. *sub*, under ; *aer*, the air) or surface agencies, which act upon the earth crust from without ; and the *Sub-terranean* (Lat. *terra*, the earth), which act upon it from within.

16. In a comparatively fixed and stable region like our own, one is apt to underrate the effects of these modifying causes. We see from our infancy the same hills and valleys, the same fields and streams, and are apt to infer that little or no change is going forward. As we note more attentively, however, we begin to perceive that changes have taken place—are yearly, daily, and hourly taking place around us. We see the river deepening its channel, the tides and waves wearing away the sea-cliffs, the frosts and rains crumbling down the rocky surface, the estuary filling up with sand-banks, and the lake in which we laved our young limbs becoming shallower, and a large portion of it transformed into a marsh, luxuriant with reeds and rushes. If all this has taken place during some thirty or forty years, what, we naturally ask, may have taken place during centuries ?—and what the amount of change, when centuries have been multiplied by centuries ? Nay, more, if a few years can work such changes in a district of

comparative rest and stability, what are we to expect over the whole surface of the globe, and especially in regions whose lakes are like our seas, and compared with whose rivers our streams are tiny threads of water—regions of extremes, where rains fall in torrents—where inundations deface, earthquakes submerge, and volcanoes give birth to new mountains? Extending his views in this manner, the attentive observer soon discovers that the surface of the earth, instead of being a thing of permanence and stability, *is subject to incessant change*; and as he carries his thoughts over the lapse of centuries, he can readily perceive how sea and land may have frequently changed places—how old mountain-ranges may have been worn down, and new ones formed—the sites of lakes become *alluvial* tracts (Lat. *ad*, to; *luo*, I wash—made by the operations of water), and the sands and muds of former shores been converted into solid strata.

17. The agents which produce these changes being universal and incessant in their action, and the cause of all geological phenomena, it is necessary the student should have a clear understanding of their nature and mode of operation. They are, as we have already noticed, most naturally arranged in two main groups—the SUB-AERIAL or exterior, and the SUB-TERRANEAN, or interior, agencies. The exterior agencies include the *Atmospheric*, or those operating through the medium of the atmosphere; the *Aqueous*, or those arising from the operations of water; and the *Organic*, or those dependent upon animal and vegetable growth. The interior agencies are the *Volcanic*, or eruptive; the sudden crust-movement, or *Earthquake*; and the slow crust-movement, or *Secular upheaval* and depression; and lastly, we have *Metamorphic* agency (Gr. *meta*, denoting change; and *morphe*, shape), which is the general term employed for those subterranean causes which bring about the gradual alteration of the original characters of deeply-buried sedimentary or igneous accumulations. If we have regard to the *manner* in which these several agencies perform their functions, we see that the subterranean agencies act only chemically and mechanically, while the superficial agencies act chemically, mechanically, and vitally. Thus geologists not only speak of *aqueous* and *igneous* rocks, &c., according to the agency more immediately concerned in their formation; but also of *mechanically-formed*, *chemically-formed*, and *organically-formed* rocks, according to their special mode of origin.

## ATMOSPHERIC AGENCIES.

18. Of the causes acting upon the earth crust from without, the ATMOSPHERIC, though not the most powerful, are by far the most general in their operations. The atmosphere envelops the earth on every side; acts mechanically by its currents of wind, chemically by the gases of which it is composed, and vitally in its being indispensable to vegetable and animal life. Thus winds blow and drift about all loose material, carrying them away from one spot, and piling them up in another. In this way extensive tracts are formed along the coasts of many countries by the landward drifting of the shore-sands. The links of Scotland—formed in this way—constitute a very characteristic feature of its eastern coast scenery. The shores of the Bay of Biscay, for nearly 100 miles N. of the Spanish border, are fringed by enormous sand-dunes. The loose arid sands of the African and Asiatic deserts, having few or no obstacles to their progress, are carried forward year after year over new expanses—hence the gradual entombment of fields, forests, and villages that lie in the way of such progressive sand-waves. A curious formation of yellowish clay, which is spread over the central parts of the Old World from Germany to China, and is known as the *Loess*, has been ascribed to this agency. In China it occasionally attains a thickness of from 1500 to 2000 feet. Again, in great volcanic eruptions the dust blown out of the crater is carried for vast distances by the wind—the atmospheric and volcanic agencies here working in harmonious conjunction. The gases of the atmosphere (oxygen, nitrogen, and carbonic acid), after they have been taken up by rain, exert a wasting or degrading effect upon all rock-surfaces; but their mode of action is best discussed under the head of aqueous agency. Almost equally important are the effects brought about among rocks and soils by changes of temperature. In countries like the Sahara and other desert regions, where the daily range of the thermometer is excessive, the alternate expansion and contraction of the surface-rocks is so great as to break them into ragged sheets, and finally to shiver them into the finest fragments.

## AQUEOUS AGENCIES.

## Weathering Action of Rain-Water.

19. The modifying causes arising from the operations of WATER are, in like manner, universal and incessant. Aqueous

agency manifests itself most pronouncedly in the *mechanical*, and less markedly in the *chemical* effects, of *rains*, *springs*, and underground waters; of streams and *rivers* of water; and *glaciers*, or rivers of ice; and in the work of the *sea*, its waves, its icebergs, its tides, and its oceanic *currents*. *Rain-water* acts both chemically and mechanically, and the general effect of its continued action on rocks and soils exposed to its influence is known as WEATHERING. In falling through the atmosphere, rain-water absorbs some of its component gases (oxygen, nitrogen, and carbonic acid), and in making its way over the surface of the ground it absorbs additional carbonic acid from decaying vegetation and the like. Rocks containing iron become oxydised (or rusted) by taking up oxygen from the rain-waters that percolate them; while calcareous or limy rocks become *dissolved* in rain-water containing carbonic acid, and are *removed in solution*. In this way some of the granites of Cornwall have been decomposed in places to a depth of 30 or 40 feet, while the separated ingredients of others are represented by thick deposits of kaolin (china clay) and masses of quartzose sand. All rocks, no matter what their lithological character, are subjected to this wasting influence. Indeed,



Fig. 2.—Showing Formation of Soil. *a*, Solid rock; *b*, Rotting rock; *c*, Subsoil; *d*, Soil.

*all the soil of our country* must be regarded as having been derived from the degradation of its rocks; for the process of weathering goes on continually below the soil itself; and in most districts a complete gradation can be traced from the surface-soil to the “subsoil” (which is generally the colour of underlying strata), and thence down into the broken and slowly disintegrating rock-surface at the base of all.

20. The *mechanical action of rain* is strikingly evident, even to the most casual observer, and is one of the most important factors in geological dynamics. Every shower that falls washes off loose particles of soil, dust, fragments of disintegrated rocks, sand, and clay, into the nearest brook, and thus bares a fresh surface to the action of the weather, to be disintegrated and washed away in its turn. The softer rocks—clays, sands, and loams—are first removed, while the harder

bands of grit, sandstone, or limestone resist much longer. But, in the course of time, even the hardest rocks succumb, and are carried off, particle by particle, to the streams, on their inevitable journey to the ocean. To this incessant action of rain and rivers, which is known to the geologist as **DENUATION**, we owe almost all the varied features of our landscape—our valleys and plains marking those areas where the strata are soft and most easily worn down, our hills and mountains those districts where the rocks are hard and intractable, their physical characters enabling them to oppose a longer and more dogged resistance to the denuding forces.

*freezing* 21. Much of the rain-water falling upon the surface of the earth sinks into cracks and crevices of the rocks, and to the presence of this moisture their eventual destruction is frequently due. As the temperature of water in winter is lowered it gradually contracts, until at  $39\frac{1}{4}^{\circ}$  (Fahr.) it attains its maximum density. As the temperature is reduced still further, however, it again increases in bulk, until at  $32^{\circ}$  (Fahr.) it *suddenly expands* and solidifies as ice. The rain-water in the fissures of the rocks is often frozen in this position, and the expansive force it exercises on solidifying is practically irresistible. It forces the rocks asunder, widening the cracks and crevices with the ice-wedge at every frost, and finally shivering the hardest rocks to fragments. In mountainous and polar regions this agency acts with remarkable effect. The exposed tops of elevations like the Rocky Mountains and the Alps are rent into jagged points and needles, and their sides covered with a long *talus* of shivered fragments.

### Springs and Underground Waters.

22. Where rain-water falls upon pervious strata, or upon strata much jointed and broken, it descends until it meets



Fig. 3.—Surface Springs. *a*, Pervious rock; *b*, Impervious stratum; *s*, Springs.

with an impervious stratum, or until its upper surface is level with a lateral outlet, where it issues forth as a *spring*. When

the supply of water is constant the spring is *perennial*, when the supply is variable the spring is *intermittent*. Sometimes the water makes its way to great depths, where it becomes heated, and is again forced upwards by hydrostatic pressure, and we have the phenomena of *hot springs*. The rain-waters, percolating

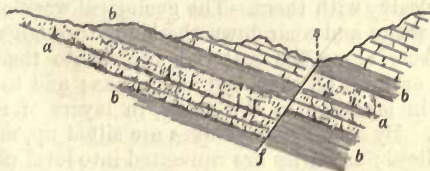


Fig. 4.—Deep-seated Springs. *a a*, Pervious strata; *b b*, Impervious strata; *f*, Fissure; *s*, Spring.

in this way through the crust, and charged with carbonic-acid and other gases, effect great *chemical changes* upon the rocks they traverse, here dissolving limestones and carrying off the carbonate of lime in solution, there removing iron, silica, or other chemical ingredients. Finally, they may issue forth as *mineral springs*—saline, chalybeate (chalybs = iron), siliceous (silex = flint), sulphurous, &c. As a general rule their waters carry off the minerals they contain to the ocean, but in some cases the excess is deposited as calcareous *travertine* or *stalagmite*, or as *siliceous sinter*. Where the subterranean waters gather into underground rivers and runnels, they dissolve and wear away the surrounding rocks into subterranean passages

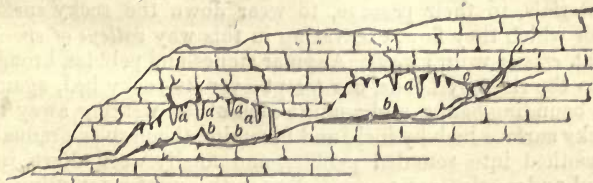


Fig. 5.—Ideal section of a Cavern. *a a*, Stalactites; *b*, Stalagmites.

or *caverns*, like that of the Peak in Derbyshire, which is 2250 feet in length and in some places more than 100 feet high; or the Mammoth Cave of Kentucky, the various branches and passages of which are said to be more than 100 miles in collective extent.

## Streams and Rivers.

23. Streams and rivers act chiefly in a mechanical way, and their influence depends (a) upon the *nature of the rocks* over which they flow, (b) their own *speed*, (c) their *volume of water*, and (d) the amount of rock *débris* or grinding material which they carry with them. The geological work of rivers is, namely, to waste and wear down the lands through which they move; to bear along the material swept into them by rains and floods, or worn off their bed and banks; and to deposit it in valleys, in lakes, or in the ocean, in layers of mud, sand, and gravel. By such deposits lakes are silted up, and become alluvial valleys; estuaries are converted into level plains; and even large tracts shoaled up and reclaimed from the sea. In brief, rivers possess three distinct functions—those of (1) *erosion*, (2) *transportation*, and (3) *deposition*. The transported materials consist of mineral matter in *solution*, a large amount of mud in *suspension*, and a smaller quantity of coarser material *pushed* along the river-bed. The river Po has been estimated to carry annually to the sea about  $\frac{1}{300}$  of its volume of sediment. The Ganges pours into the sea annually a mass of material in suspension which would form a column a mile square and 225 feet high. How much additional matter these rivers carry in solution is as yet unknown, but the average quantity for all the rivers of the globe has been estimated at  $\frac{1}{5000}$  by weight.

24. Not only do rivers thus transport materials from higher to lower levels, and deposit them in still waters to form new sedimentary accumulations, but they employ the moving solid materials, in their passage, to wear down the rocky surface over which they flow, excavating in this way *valleys of erosion* (Lat. *erosus*, worn away). Angular stones and pebbles, brought into the river by floods, are swept over its rocky bed, against its bounding-banks, and against each other, wearing away the rocky surface inch by inch, and becoming themselves gradually smoothed into rounded pebbles, and finally worn down into sand and carried out to sea. By far the most astounding examples of river erosion are seen in the famous cañon of the Colorado and its branches. The main cañon, which is wholly the work of this great river, is more than 300 miles in length, and is dug out of massive formations of sandstone, limestone, and granite. It consists of an upper valley several miles in breadth, bounded by cliffs, and a lower or interior ravine, the total depth being about 6000 feet. It is associated with a

countless number of similar and tributary gorges, of similar origin and almost equal importance.

25. The *slope* of a river-bed, and the *amount* of the erosion of its bed and banks, usually vary greatly in various parts of its course. This difference depends generally upon the *varying resistance to erosion* of the strata over which it flows. If the strata are soft and easily eroded, the river-bed is soon cut down to the base level of erosion, and the neighbouring valley is widened by the action of the weather. But where the strata are relatively hard and compact, the river valley is narrow and deep, and the water is arrested by rapids and waterfalls. Of this feature we have abundant instances in our British river courses—in the rapids of the Clyde near Lanark, and in the turbulent stream and deep gorge of the Spey, as contrasted with the soft-flowing Avon, or the gently-moving, broad-valleyed Thames. Where a hard stratum rests upon one of a softer nature, erosion is arrested above and behind, while it goes on unchecked in front and below, and the river-waters plunge in a foaming *waterfall* from the hard stratum into a deep hollow worn in the softer mass beneath.

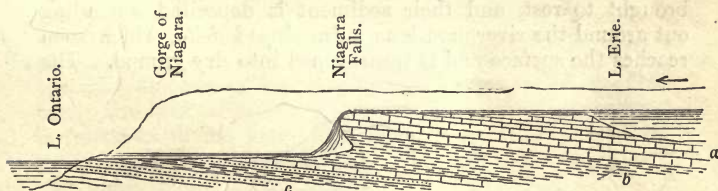


Fig. 6.—Section of the valley and gorge of the Niagara River. *a*, Hard Niagara limestone; *b*, Soft Clinton shales; *c*, Medina sandstones and shales.

This is the origin of the majority of waterfalls and cascades, and is strikingly illustrated by the great falls of the Niagara, the waters of which plunge down from the upper face of a mass of limestone into a bed of soft shaly rock 200 feet below.

26. So long as the waters of a river are in rapid motion they carry the sediment in suspension; but, where from any cause, whether by entering a level plain, a lake, or the sea, their motion is arrested, the *sediment falls to the bottom* in the form of gravel, sand, or mud. Where rivers are naturally unconfined they overflow their banks in their lowland courses in flood times, and fling down their load of sediment upon the surface of the flooded lands. This is the origin of our carse and haughs, and is the source of most of the fertile meadows

of Britain. When the river-course becomes deepened, or its channel receives a steeper slope, the waters of the river cut away much of this alluvial soil and form a newer and lower

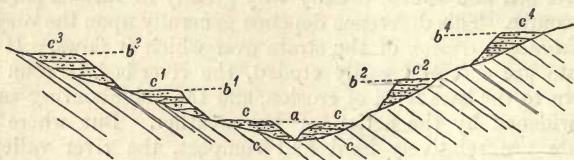


Fig. 7.—River Terraces. *a*, Present flood-level of river; *b¹*, *b²*, &c., Former flood-levels of river, or lateral terraces; *c*, Gravel of present river; *c¹*, *c²*, *c³*, Earlier gravels of river.

range of meadows nearer to the river-bed. In this way patches of uneroded older meadow-land are left behind in the form of grassy river terraces; the highest terrace being of necessity the oldest, and the lowest the youngest of the meadow flats which were formed by the river as it deepened its valley.

27. Where the river waters enter a lake they are at once brought to rest, and their sediment is deposited, spreading out around the river-mouth as a *fan-shaped delta*, which soon reaches the surface and is transformed into dry ground. The

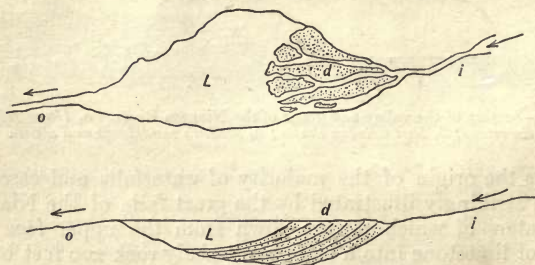


Fig. 8.—Sketch-Map and Section, showing formation of delta and silting up of a lake. *L*, Lake; *d*, Delta; *i*, Inflowing river, waters charged with mud and silt; *o*, Outflowing river, waters clear.

process continues until the entire lake is silted up to the level of the river floods, and its place marked by a broad fertile tract of meadow-land. Where the waters of a river enter the sea the same action takes place, but the work performed is infinitely more important, and is complicated by many natural

causes. If the estuary is deep the outflowing waters of the river are first brought to rest where their movement is neutralised by the incoming tides or sea-waves. At this point the sediment suddenly falls to the bottom, and a long mound or *bar* of sand is piled up across the river-mouth, almost level with the surface of the water and acting as a serious hindrance to navigation. Where, as in the case of the Amazon and Orinoco, a swift current sweeps past the mouth of the river, the sediment is carried off and spread equally over enormous areas of the sea-bed; but where no currents exist, the sea is comparatively shallow, and the sediment large in amount, it is all thrown down in front of the river-mouth.

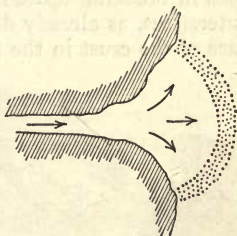


Fig. 9.—Showing formation of Bar at river-mouth.

When this is the case the river becomes blocked by the sediment, and divides into two branches which make their way out to sea on opposite sides of the obstruction, forming what is known as a *delta* (so called from its resemblance to the Greek letter  $\Delta$ , *delta*). But the mouth of each of these arms becomes blocked in its turn; and thus the river is forced to divide and subdivide again into innumerable mouths and branches. The area of the united delta of the Ganges and Brahmapootra formed in this manner is estimated at above 50,000 square miles, that of the Mississippi at 12,300 square miles. The latter is advancing seaward at a rate of more than 200 feet every year. The Po-Adige delta in northern Italy has reclaimed a breadth of from 2 to 20 miles of land from the sea within the last 2000 years, and the Roman seaport of Adria, which gave its name to the Adriatic Sea, is now actually 20 miles inland.

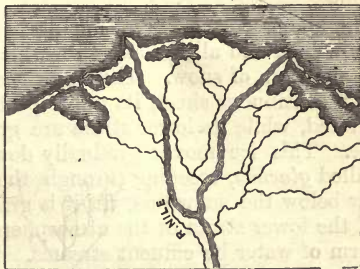


Fig. 10.—Delta of the Nile.

## Work of Ice.

28. Turning next to the action of *frozen water* or ice as a geological agent, we find that ice acts not only below the surface in breaking up the rocks when formed in their joints and interstices, as already described, but works also above the surface of the crust in the form of *glaciers*, *ice-sheets*, and *icebergs*.



Fig. 11.—*Junction of Glaciers exhibiting lines of medial moraines.*

The higher parts of great mountain areas usually lie above the snow-line, and all the moisture which falls upon them settles in the form of snow. This snow accumulates year after year in a continuous sheet, its upper portions being loose and unaltered, while its lower strata are gradually consolidated into ice. This ice moves gradually downwards in long tongues called *glaciers*, creeping through the chief mountain valleys, far below the snow-line, till it is gradually melted by the heat of the lower strata of the atmosphere, and is carried off in the form of water by effluent streams. The motion of the ice in a glacier resembles that of the motion of water in a river, the middle of the glacier moving much more rapidly than the sides, but yet with exceeding slowness, at most in Switzerland from 20 to 27 inches in 24 hours. As the glacier travels below the snow-line, blocks of rock fall upon it from the naked cliffs that bound it, and a long line of rocky fragments is formed along each margin. These are slowly carried downward and constitute a *lateral moraine*. When two glaciers unite, their lateral moraines combine at their point of juncture and are carried forward as a single line down the central part of the united glacier, forming what is called a *medial*

*moraine.* The number of these medial moraines is an index of the number of independent glaciers of which a large glacier is composed. All the material of these moraines is at last thrown down at the foot of the glacier in a crescentic mound, which is known as a *terminal moraine*.

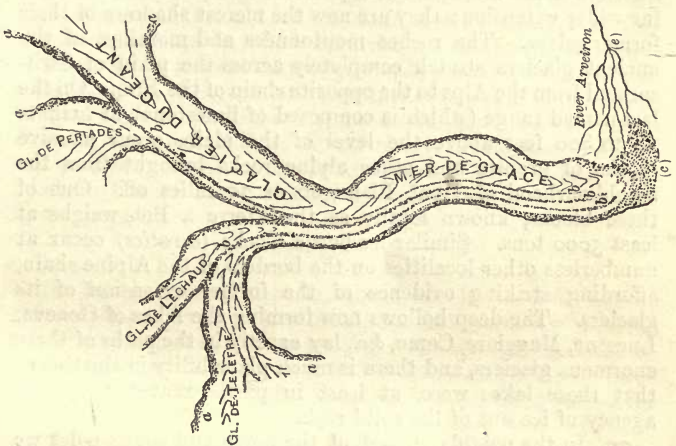


Fig. 12.—The Mer de Glace and its branches, showing—*a*, Lateral moraines ; *b*, Medial moraines ; *c*, Terminal moraine ; *e*, Effluent stream.

29. Owing to the difference in the rate of movement between the lateral and central parts of a glacier, enormous cracks termed *crevasses* are formed in its substance. Down these cracks fall some of the rocky fragments from the superficial moraines. These fragments become frozen into the bottom layers of the glacier, and are forced downwards by the moving mass of ice above, over the rocky floor of the valley, scratching, grooving, and grinding away its surface, and becoming themselves grooved and scratched in their turn. In this way the valley is deepened year by year, and all prominences in the path of the glacier have their irregular edges and angles worn and smoothed, and their surfaces polished and rounded. Such smoothed rocky protuberances are conspicuous phenomena in the paths of ancient glaciers, and are known as *roches moutonnées* (from their resemblance to the backs of sheep). The eddies and hollows in the path of the glacier become filled up with a dense mass of clay and boulders worn off the sur-

rounding rocks and intensely compacted by the ice-pressure: this material constitutes what is called the *ground moraine*. The waters which flow out from below the melting glacier-ice are thick and turbid with their charge of fine glacial mud. The modern glaciers of Switzerland and other mountainous districts of the northern hemisphere had in prehistoric times a far wider extension: they are now the merest shadows of their former selves. The *roches moutonnées* and moraines of the ancient glaciers stretch completely across the plain of Switzerland from the Alps to the opposite chain of the Jura. On the last-named range (which is composed of limestone), at heights up to 800 feet above the level of the plain, occur massive blocks of granite and other alpine rocks brought from the neighbourhood of Mont Blanc, 60 or 70 miles off. One of these blocks, known locally as the *Pierre à Bot*, weighs at least 3000 tons. Similar ice-borne blocks (*erratics*) occur at numberless other localities on the borders of the Alpine chain, affording striking evidence of the former extension of its glaciers. The deep hollows now forming the lakes of Geneva, Lucerne, Maggiore, Como, &c., lay exactly in the paths of these enormous glaciers, and there is much plausibility in the theory that these lakes were, at least in part, excavated by the agency of ice out of the solid rock.

30. In the neighbourhood of the north and south poles we see still existent the climatic conditions that must once have prevailed in Switzerland, and we find as a consequence the land in these regions swathed in a perennial *ice-sheet*, moving outwards from the central high grounds towards the sea. The Antarctic continent is buried under an ice-pall estimated at

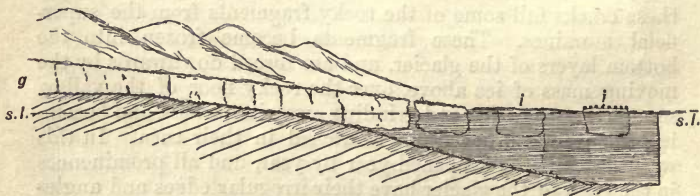


Fig. 13.—Ideal section of Greenland glacier giving origin to icebergs. *g*, Glacier; *s.l.*, Sea-level; *i i*, Icebergs.

two miles in thickness, which gives rise to glaciers more than 50 miles in width, off which mighty fragments, many square miles in extent and of enormous thickness, float away sea-

ward in the form of *icebergs*. The central parts of Greenland are buried beneath an ice-sheet of similar character, and its icebergs, charged with their load of rock fragments, float southwards till they are melted in the warm Gulf Stream off the coasts of Newfoundland. Their earthy debris is spread out in a broad sheet over the ocean floor, there to form an important part of the rocky formations of our future lands. In the great Ice Age (in which occurred the extraordinary development of the ancient Alpine glaciers), ice-sheets, comparable with those of the Antarctic continent and Greenland, seem to have covered both the European and American continents down to the parallel of  $52^{\circ}$  N. latitude, and the masses of clay and northern boulders now found spread over Britain and northern Europe are evidences of their action and their enormous extension.

#### Waters of the Sea.

31. The waters of the sea, like those of the land, act in three distinct ways. They break up and *erode* the rocks of the shore-line, they *transport* the disintegrated material to fresh localities, and they *deposit* it again as sheets of incoherent sediment, ready for reconsolidation and *re-upheaval* as rocks to form the framework of a future land. In this work *wind-waves, tides, and currents* all bear a part. The wind-waves erode the rocks of the shore, the tides and currents transport and distribute the disintegrated materials. The work of destruction is almost wholly confined to the edge of the land, and to the small margin exposed between the rise and fall of the tide. In this work the wind-waves take the greatest share. The average force of the blow delivered by the ground-swell of the Atlantic sweeping in upon the west coast of Scotland is estimated at 611 lb. per square foot in summer, and 2086 lb. (or nearly a ton) in the winter months. In times of storm and tempest, wave after wave of even greater power is hurled in upon the shore-line, upon the exposed cliffs, like the successive blows of a battering-ram. The pebbles, the blocks of loose stone, and the massive boulders, are lifted by the wave and dashed against the shore. Fragments of the rocky cliffs are broken off, their softer portions are dug into, the overhanging masses are undermined, and finally topple headlong into the breakers in a shower of fragments, each of which becomes in its turn a weapon for further destruction. By the never-ending swing of the waves, these rocky fragments are soon rounded into pebbles, the

pebbles are worn down into sand, and the sand is finally swept by the under-tow far out to sea. In districts where the strata are comparatively soft, the sea-waves in this way soon effect their destruction, and their place becomes occupied by a sandy beach. Where the rocks are highly indurated and resistant, they rise up for a time in perpendicular cliffs, like the chalk precipices of Flamborough, Beachy Head, or Dover ; but their destruction, though slower,



Fig. 14.—Coast-line, showing the effects of wave-action in the formation of arches, stacks, and needles.

is merely a question of time ; stage by stage they are cut down into sea-washed “stacks” and “needles,” finally to disappear from sight altogether beneath the all-devouring waters.

32. The present headlands of Britain mark the actual places of its harder and more resistant rocks ; its bays and inlets the places of its softer strata. Towards the fierce Atlantic look out the rugged cliffs of Cornwall and the Hebrides, their granitic and gneissic rocks bidding for a time defiance to the ocean. But the softer sandstones of the Orkneys are carved into perpendicular cliffs, some of them upwards of 1200 feet in height ; and the islands are melting almost visibly before the onslaught of the ocean. Towards the shallower and narrower North Sea, the shore-line of Britain is less bold, only the hard strata of sandstone and chalk which relieve its masses of softer rock rising in points of cliff, between the long and gentle stretches of sandy shore. But even this coast is being cut away by the waves with great rapidity. The shoreland between Flamborough and the Humber is said to have lost a mile in breadth since the Norman Conquest. Some parts of the coast of Norfolk are wasting annually at the rate

of about 14 feet; and tradition asserts that the Goodwin Sands, now five miles off the Kentish coast, formed a part of the mainland as late as the period of Edward the Confessor.

33. The materials worn off the shore-line, and the gravel, sand, and mud brought down by rivers, are all deposited upon the floor of the ocean. The pebbles and coarser materials accumulate along the edge of the land, forming *shingle beaches*, and broad expanses of gravel in shallow waters. The most remarkable of these shingly accumulations on the British coast is the Chesil Bank. This extends along the coast of Dorset for a distance of 17 miles, and has a height of about 25 feet, and a width of between 500 and 600 feet. Shallow and protected expanses along the shore-line, like the ancient estuary of the Wash, become silted up and transformed into broad stretches of *fen-land*. Shallow seas, like the German Ocean, become filled with sandbanks and *shoals*, of which we have striking instances in the shoals off the estuary of the Thames, and the great Dogger Bank between Scotland and Holland. The deeper hollows, like the central parts of the English Channel, St George's Channel, and the Irish Sea, become covered with broad expanses of river mud. Every sea-surrounded coast has its fringe of shore-derived materials, extending outwards from the margin of the land for a distance of from 50 to 150 miles to sea, the materials being arranged, broadly speaking, in the order of their coarseness—the shingle and gravel nearest the shore, the sand in the intermediate areas, and the muds and clays in the more distant and deeper waters, locally intermingling and overlapping as the local conditions change and vary. But everywhere there comes a limit to the seaward extension of even the finest mechanical sediment, and at a distance of less than 200 miles from land it entirely disappears; and the deeper abysses of the ocean contain only deposits derived from the decay of oceanic animals and plants, mixed with the dust carried by the winds from the grander volcanic eruptions.

## ORGANIC AGENCIES.

34. The ORGANIC AGENTS tending to modify the crust of the globe are those depending on vegetable and animal life. The term organic (from the Greek *organon*, a member or instrument) is applied to plants and animals generally, as being supplied with certain organs or members for the purposes of nutrition and growth, &c. Their structure is said to be or-

*ganic*, and they are termed organised bodies in contradistinction to minerals, which are *inorganic*, and whose increase takes place by external additions, and not through the instrumentality of any peculiar organs. *Vegetables* by their growth and decay are yearly adding to the soil, at the same time that they protect its surface from the wasting action of rain, frost, and the like. Accumulations of plant-growth form peat-mosses, jungle, cypress, and other swamps; and the spoils of forests and the vegetable drift of rivers form rafts (like those of the Mississippi)—all of which are adding to the solid matter of the globe. Coal, as will afterwards be seen, is but a mass of mineralised vegetation; and under favourable conditions, and in course of time, submerged peat-mosses, jungle-growths, forest-growths, and drifted rafts would form similarly mineralised deposits. As vegetable growth is specially influenced by heat, moisture, and conditions of climate, so in certain regions will the effects of vegetation, as a modifying cause, be more perceptible than in others.

35. As familiar instances of *vegetable* agency, we may point to the peculiar plants that spring up on the newly-formed sand-dunes by the sea-shore, and protect the surface from being blown and scattered about by the winds; to the peat-bogs of Ireland, Scotland, Holland, Canada, and other coldly-temperate countries, often extending over thousands of acres, and varying from ten to forty feet in thickness; to the pine-rafts yearly floated down by the Mississippi; to the cypress-swamps of America—the “Great Dismal,” for example; to the “tarai” or jungle-swamps of India; to the “sudd” or matting of grasses which chokes the upper reaches of the Nile and other waters of tropical Africa; and to the mangrove-growth that binds and protects the mud-flats and islands of such deltas as those of the Ganges, Irawaddy, and Niger. All these growths are slowly but continuously adding to the crust, and though the amount may be small compared with mechanically-formed sediments, yet geologically and industrially it is of the highest importance. Besides the carbonaceous or coaly deposits formed by the growth of the higher plants, siliceous or flinty accumulations take place in lakes, marshes, and fresh-water estuaries through the growth and decay of microscopic forms (the diatoms), whose tiny frustules constitute beds of earthy matter (microphytal earths—*mikros*, small, *phyton*, plant), analogous to the mountain-meal (*bergmahl*) of the Swedes, the edible clay of the Indians, and the polishing slate of Tripoli. Even in the ocean itself the dia-

toms are busied in forming new and widely extended deposits. South of the Cape of Good Hope the deep-sea ooze is formed of the skeletons of diatoms, at depths varying from 8000 to 12,000 feet, and over an enormous expanse of the ocean floor.

36. The manner in which *animals* tend to modify the crust of the globe, is chiefly by adding their protective secretions or coverings. It is true that the bones and other remains of the larger animals are often buried in the mud of lakes and estuaries—there in time to form solid petrifications; but such results are lithologically trifling (that is, in a rock-forming sense—*lithos*, a stone), compared with shell-beds, foraminiferal accumulations, and coral-reefs. Thus the *shells* of gregarious shell-fish—as oysters, cockles, and mussels—form beds of considerable thickness, and, if entombed among the silt of estuaries, will in time originate beds of shelly limestone like those occurring in the solid crust of the earth. Masses of drift-shells occur less or more along the sheltered recesses of every sea-shore, and these, in like manner, when covered up and consolidated, will be converted into impure limestones. Recent discoveries have also shown that vast accumulations of whitish chalky mud occurring in the deeper bed of the Atlantic and other oceans are composed of the calcareous shields of *foraminifera* (*foramen*, an opening, from the punctures in their shields through which they protrude their pseudopodia). This calcareous mud or ooze spreads almost universally over the floor of the great oceans between the landward fringe of shore-derived detritus and those interior abysses which are more than 12,000 feet in depth. It is a soft sticky mud, of a greyish-white colour, and when dried resembles powdered chalk. Under



Fig. 15.—Organisms in the Atlantic Ooze, chiefly Foraminifera (*Globigerina* and *Textularia*), with *Polycystina* and sponge-spicules; highly magnified.

the microscope it is seen to be almost wholly made up of the stony shells of foraminifera—the vast majority belonging to the genus *Globigerina* (see fig.): hence its common designation as the *Globigerina* ooze. These foraminifera live

mainly upon the surface of the ocean, their shells falling to the bottom after death, and some idea of their minute size may be gathered from the fact that 10,000 of them placed side by side would hardly cover the space of a square inch. It is thus a microzoal earth (*mikros*, small, *zoön*, animal), analogous to the chalk of the south of England—the greater proportion of which is composed of the shields of similar

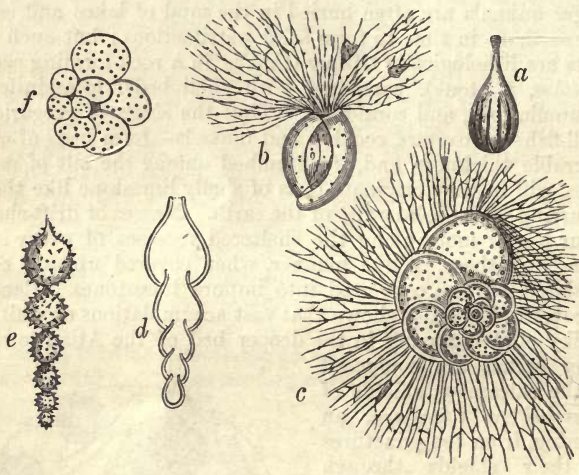


Fig. 16.—Forms of existing Foraminifera. *a*, *Lagena vulgaris*; *b*, *Miliola*, showing the pseudopodia protruded from the oral orifice; *c*, *Discorbina*, showing pseudopodia protruded from foramina in the shell-wall; *d*, Section of *Nodosaria*; *e*, *Nodosaria hispida*; *f*, *Globigerina bulloides*.

foraminiferal organisms. When treating of the older rock-formations, we shall see what an important part these minute organisms (vegetable and animal) have played in adding to the solid masonry of the globe. At depths of more than 12,000 feet enormous expanses of the ocean floor are covered with what have been termed *Abysal* deposits; and they appear to constitute the most widely extended of all the deposits now in process of formation. They consist mainly of impalpable red and grey clays. Their origin cannot yet be regarded as satisfactorily determined, but according to the highest authorities they are mainly composed of volcanic dust with a certain proportion of siliceous and ferruginous material, derived from the decomposition of the shells of Foraminifera. Finally, in

a few of the deeper soundings we find a siliceous ooze mixed in part with the red clay. This consists of the siliceous skeletons of minute forms of Radiolaria, and is known as the *Radiolarian ooze*.

37. One of the most wonderful exhibitions of animal agency is that of the Actinozoon (rayed animal) known as the coral zoophyte. Endowed with the power of secreting carbonate of lime from the waters of the ocean, the coral animal rears its *polypidom*, or stony support (Lat. *polypus*, and *domus*, a house), in the warmer latitudes of the ocean—and there constructs reefs and barriers round every island and shore where conditions of depth and current are favourable to its development. Many of these reefs extend for hundreds of leagues, and are of vast thickness, reminding one of the strata of limestone belonging to the older formations. The true reef-building zoophyte is apparently limited in its range of depth, operating upwards only where covered by the

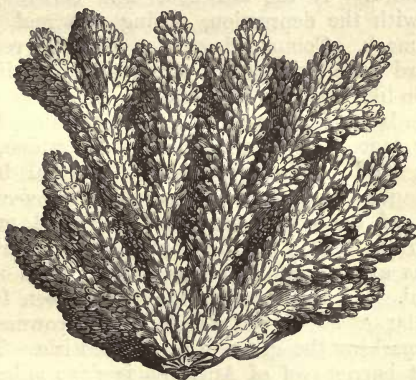


Fig. 17.—Fragment of Madrepora Coral.

tide, and downwards to eighteen or twenty fathoms. Within this range it is ceaselessly active,—elaborating carbonate of lime from the ocean, and converting it into a home for itself and its myriad progeny. Let any one examine a piece of Madrepora coral, count the number of cells or pores in it, remember that each pore is the abode of an independent but united being, and then reflect on the thousands of miles of coral-reef now in process of formation, and he will be lost in wonder at the numerical exuberance of animal life.

The coral-reef occurs in all stages of development, from the living and growing clump to a compact and solid aggregation of limestone scarcely to be distinguished from some of the softer marbles. Partaking of the elevation or depression of the sea-bottom, and being subject to the influence of the waves and breakers, a coral-reef is not a mere narrow ledge composed of various beautifully-formed corals, but a barrier of limestone more or less compact, mingled with its own surf-worn debris, with shells, sponges, sea-urchins, and other marine *exuviae* (Lat. cast-off crusts), and often presenting a surface above the waves weathered and converted into soil capable of sustaining a scanty vegetation. The corals which produce such a reef grow on the seaward edge of land, building up a reef composed of their united skeletons upon the sea-level, where the growth of the animal is arrested. According to Darwin's simple and beautiful theory, if the land is stationary and the sea shallow, the reef grows outwardly seaward. If the sea-floor sink slowly the corals keep pace with the depression, raising the reef always to high-water mark. Commencing as a *fringing* reef, with a high seaward edge, where the strongest corals live, and a lower lagoon-like interior towards the land, the outer reef grows upwards vertically as the land becomes depressed, and the interior lagoon appears to deepen and widen, until the diminishing land is separated from the coral bank by a concentric lagoon, and the reef becomes a *barrier* reef. As the process of depression continues, the land may wholly disappear from sight, and the central lagoon develop into a continuous expanse of water, encircled on all sides by a ring of coral. — In this manner may have been formed the lovely circular *atolls* of the Pacific, palm-crowned rings of coral, each marking the grave of a vanished isle. The length of the great barrier-reef of Australia is 1250 miles; and its oceanic margin rises from a depth of nearly 12,000 feet. But satisfactory and simple as Darwin's theory appears, its general application has been called in question by Mr Murray of the Challenger Expedition, who points out that the peculiar phenomena of coral-reefs do not necessarily imply subsidence, for the Pacific reefs are usually formed around volcanic islands. In the cases of a fringing-reef (see par. 61) and a barrier-reef the original nucleus of the volcanic land is still visible, and the lagoon in the latter case may have been formed by the solution of the coralline matter by the aid of the carbonic acid of the inner waters. In the case of the atolls

and widespread coralline sheets, the original land may have been cut down to the sea-level, or below, by wave-action, before the corals began to build. Or, again, submarine volcanoes, shoals, and platforms may have had their upper surfaces raised to the limit at which corals build by the gradual deposition upon them of the shells and stony coverings of the abundant organisms present in the surface waters of the ocean. The most striking example of the actual formation of new land by organic agency in the last of these suggested modes is seen in the case of the peninsula of Florida, the southern portion of which, to the extent of between 12,000 and 15,000 square miles, has been thus reclaimed from the sea in recent geological times. Coral-reefs are first formed on submarine platforms whose upper surface has been raised by the successive deposition of layers of sea-shells, &c. These reefs coalesce into a chain of islands (*keys*), having between them and the land a shallow lagoon. This is slowly filled up by coralline material largely drifted in by the sea-waves, and finally all is added to the mainland.

## CHEMICAL AGENCIES.

38. The modifying causes resulting from CHEMICAL ACTION are numerous and complicated. Thus, the accumulation of the coral-reef is partly a chemical process ; the operations of all mineral springs are more or less chemical ; and some of the phenomena connected with volcanoes and earthquakes may arise from a similar source. Laying aside, in the meantime, the changes taking place in the interior of the rocky crust, by which some strata are consolidated and hardened, others softened and dissolved away, metallic veins formed, and new compounds elaborated by the union of different substances, we shall confine our remarks to those chemical results which chiefly appear on the surface. The formation of the coral-reef, we have said, is partly a chemical process. The limy matter is no doubt secreted by the polype, but its subsequent consolidation into a compact rocky mass is the result of chemical action among the particles of carbonate of lime, of which it is almost wholly composed. The same sort of consolidation is brought about among littoral shell-beds and calcareous sands, often rendering them as hard and compact as ordinary building-stone, and thus forming *littoral* or *shore-formed concrete* (Lat. *littus*, the shore). Deposits of limestone from what are termed calcareous or petrifying springs are strictly

of chemical origin, as are also the *stalactites*, arising from the dropping of calcareous water from the roofs of caverns, and the *stalagmite* (Gr. *stalagma*, a drop) which incrusts their floors. Such spring-waters deposit calcareous tufa or calc-tuff, and the compact *calc-sinter* (Ger. *sintern*, to petrify), or *travertine* of Italy, which sometimes occurs in such thickness and solidity that it is utilised as a building-stone. As with limestone, so in like manner with silica—many hot springs, like those of Iceland, have formed vast deposits of *siliceous sinter*, one of which is estimated at 16 miles long and 100 feet thick; or those of New Zealand, which gave rise to the formerly beautiful terraces of Rotamahana; or those of the remarkable Yellowstone Park of America, where they have formed enormous deposits of the most striking and beautiful tints. Waters of lakes and inland seas, which are carried off by evaporation, increase in salinity in the course of time, and eventually the excess of salt is deposited. This has probably been the source of our British strata of *rock-salt*. To a corresponding origin must be attributed also the vast sheets of *gypsum* occasionally met with in sedimentary strata. Under the same head of chemical formations must also be classed all asphaltic or *bituminous* exudations, like the pitch-lakes of Trinidad and Barbadoes, the *petroleum* accumulations of America, the *naphtha* springs of Baku, and the like.

## RECAPITULATION.

39. In the preceding chapter we have given a general epitome of the work of those EXTERNAL, *sub-aerial*, or surface agencies which are busied in modifying the exterior of our globe. They embrace the *atmospheric*, the *aqueous*, the *organic*, and the *chemical*. Of these the ATMOSPHERIC includes the effects of *wind* in forming dunes, patches of blown sand, vast wide-spreading deserts, and deep deposits of dust, like the Loess of Europe and China. The *gases* of the atmosphere, oxygen, nitrogen, and carbonic acid, act chemically, breaking up rock-combinations, and preparing rocks for their removal, grain by grain, by rain and rivers. By its great *changes of temperature* the atmosphere causes the alternate contraction and expansion of rocks, and aided by the force of freezing water, ultimately shivers them into the smallest fragments.

40. But the grandest of all sub-aerial agents is WATER in all its varied forms. *Above ground*, in the form of *rain-water*, charged with atmospheric gases, it acts *chemically*, dissolving

and weathering away all exposed rock-surfaces, crumbling the strata to dust, and forming in this way our clays, sands, and fertile soils. Acting *mechanically*, it sweeps the loose material into the nearest streams, laying bare fresh surfaces for denudation, and giving rise to all the varieties of surface-form and scenery. *Below ground*, rain-water is for ever percolating to lower and lower levels, forming caverns and subterranean stream-courses, then emerging in the form of springs, perennial or intermittent, fresh, or charged with mineral matters, iron, silica, carbonate of lime, and finally depositing, as their water evaporates, siliceous sinter or vast beds of limy travertine.

41. The action of *running water* in streams and rivers is of the highest geological importance. Rivers waste and wear down their banks and the sides of their valleys (*erosion*), hurry all loose materials into the nearest sea or lake (*transportation*), where they sink to the bottom (*deposition*), to form the rocks of a future date. These materials are transported in *solution* (silica, carbonate of lime, &c.), or in *suspension* (mud and silt), or are rolled along the river-bed (pebbles and sand). With these materials the river digs out valleys of erosion, cañons, and ravines. Where a hard rock arrests this erosion, we have cascades and waterfalls; where the valley is broad, we have meadows and carses. Reaching the sea the river waters finally come to rest, and the loose materials are deposited in the form of bars, sandbanks, and deltas.

42. The work of *frozen water* is apparent in the effects of ice-fields, icebergs, and glaciers. The *iceberg* scatters, as it melts, its burden of debris over the ocean floor; the *glacier* transports material *on its surface* in lateral and medial *moraines*, and flings them down in a heap known as the *terminal moraine*; while *below* it the stones of the *ground moraine* erode the valley bed and form a muddy silt, which is carried off by the stream which issues from the foot of the glacier. The *ice-sheets* occur at the present time only in polar regions, but in the great *Ice age* they extended outwards in all directions from our mountain-ranges, and radiated from the N. pole on both continents down to the parallel of  $52^{\circ}$  N. Turning next to the *waters of the sea*, we find the *wind-waves* armed with sand and pebbles, wearing away foot by foot the shore between tide-marks, originating beaches, cliffs, and needles; and the *tides and currents* sweeping the debris out into the great depths to form pebble-beds, sandbanks, and submarine sheets of silt and clay.

43. Next, we have those agencies collectively known as ORGANIC. On land the work of *plants* is apparent in the formation of peat-mosses, cypress swamps, and other deposits of vegetable matter, destined in the course of ages to be transformed into coal. Among *animals* we find shell-fish originating masses of limestone and calcareous rocks, the coral polype building up enormous coral-reefs, and the sponges, foraminifers, and radiolarians laying down sheets of mineral matter far and wide over the ocean floor. Finally, we find CHEMICAL, in combination with Organic and Aqueous agencies, busied in forming littoral concrete, calcareous stalactites, stalagmite, and travertine; deposits of siliceous sinter; and formations of rock-salt, gypsum, petroleum, naphtha, &c.

## CHAPTER III.

### DYNAMICAL GEOLOGY (*Continued*).

#### SUBTERRANEAN OR INTERNAL AGENCIES.

44. HITHERTO we have concentrated our attention upon the External or Aqueous agencies, which are busied in wearing down the higher portions of the earth crust, and transporting the materials to lower and lower regions; ever tending to reduce the land to one smooth and uniform level. But this lowering tendency of the *external* agencies is continually opposed and counteracted by an antagonistic set of *internal* agencies, which are equally busy in elevating the surface, and bringing fresh materials from below to replace those removed by denudation. These internal agencies are—the *Volcano*, the sudden *Earthquake*, and the slow, long-continued *Crust-creep*. The volcano pours forth local floods of steam, ashes, and lava; the earthquake suddenly upheaves large districts; and the crust-creep, whose effects are only perceptible after the lapse of ages, bends the solid earth crust into vast waves of alternate elevation and depression, to form new continents, islands, and seas. While the meteoric agents of decay have their origin in the atmosphere, which everywhere envelops our globe without, the volcanic agents of upheaval have their origin in the deep-seated regions far below the surface. The unchecked effects of the external agencies are degradation, destruction, and unbroken uniformity. The results of the internal agencies are elevation, reparation, and scenic variety. By the one set of agencies the ruins of the land are deposited as unconsolidated sediments upon the depths of the ocean floor; by the other, they are compressed and consolidated into rocks, and again lifted above the surface of the ocean, there to undergo the same sequence of de-

gradation, deposition, and renewal. By these two antagonistic sets of forces the surface of the earth is ever kept in habitable equilibrium: and both are equally necessary in the economy of our globe.

45. Concerning *the origin of the globe* itself, geology is silent. According to the illustrious James Hutton, "it is not the province of geology to discuss the origin of things." It endeavours to read the past history of the globe, in so far as that history is revealed in the rocks and rock-formations, and it interprets the appearances these rocks present by noting the agencies and processes by which rocks and rock-formations are formed at the present day. To the action of *present causes* all geological phenomena are referred; and where peculiar phenomena are met with in the rocks which appear to demand agencies not presently in action, the cautious geologist of the present age, unlike some of his predecessors, simply confesses his ignorance, and waits patiently till the phenomena find their natural interpretation. That our earth had a beginning, that it is passing through a gradual natural development, and that it is destined, some day, to come to an end, may be regarded as certain. But, so far as our science has yet been able to investigate, the same laws that rule in the physical and vital development of the earth and its inhabitants at the present day appear always to have obtained, from the very commencement of the fossiliferous formations.

46. *The form of our globe* is that of an oblate spheroid. Its polar diameter is about 7925 miles, and its equatorial diameter 7899 miles. Thus the polar diameter is about 26 miles shorter than the equatorial, or about  $\frac{1}{360}$  of the whole. Now this is precisely the amount of polar flattening which the earth would undergo were it a viscous or plastic mass rotating at its present velocity. From this it has been argued by some that the earth was once a molten semi-fluid or more or less plastic body, and that it is slowly parting with its original heat, the exterior parts having cooled down into a solid crust, while the interior is still in a plastic, or at all events, in an intensely heated condition.

47. The actual existence of the *internal heat* appears to be demonstrated by (a) the existence of *volcanoes*, which occur at the most widely separated parts of the globe, and which clearly derive their heat and molten matter from below its surface; (b) the presence of *hot springs*, not only in the neighbourhood of volcanoes, as the geysers of Iceland, but also at such localities as Bath (120° Fahr.) and Buxton (82°

Fahr.), which are distant nearly a thousand miles from the nearest volcano; and (c) the rapid *downward increase of temperature* in borings, wells, and mines. In all regions there exists of necessity a *zone of invariable temperature* a few yards below ground, above which the crust is affected by the seasonal changes of temperature, but below which the temperature is that locally proper to the earth crust. It is found that in proportion as we descend below this line of invariable temperature, the temperature *rises*, at an average rate which has been estimated at one degree Fahrenheit for every 60 feet of descent. Local conditions cause variations in this proportion, but it is rarely or never higher than one degree for 40 feet, or lower than one degree for 80 feet of descent.

48. Of the solid state of the external or rocky portion of the earth crust there is no room for doubt, but of the condition of the *earth's interior* very different views have been held. It was formerly believed by many that the interior of the earth is *molten and surrounded by a solid crust*. This view was founded principally on the fact that if the temperature continually rises as we descend in the proportion given above, at the depth of about 20 miles the ordinary metals would become molten, and at a depth of 50 miles all bodies would become liquefied. The circumstance that volcanoes obtain their molten supplies from the earth's interior, and that the shock of an earthquake is felt over a broad area of the earth's surface, both appear also to find their natural explanation on the supposition of a thin crust resting on a liquid. Finally, while the density of the rocks of the accessible earth crust averages from  $2\frac{1}{2}$  to  $3\frac{1}{2}$ , the density of the earth as a whole is about  $5\frac{1}{2}$ , a fact which harmonises well with the theory of a lighter solid crust floating upon a heavier liquefied interior. Against this theory it has been urged that if the crust were so thin as is required by this hypothesis, it would be lifted up and down by internal tides, generated by the influence of the moon and sun in the mass of liquefied material below. Prof. Hopkins of Cambridge calculated that the crust must be at least from 800 to 1000 miles in thickness to resist this tidal action. Prof. Sir W. Thomson argues in favour of the view that the earth has a crust from 2000 to 2500 miles thick, or is even solid to the centre, and he shows that as a whole it is more rigid than a globe of glass of the same diameter. At the present day it is held by the majority of physicists that the globe is *practically solid* throughout. The solidity of the internal portions, in spite of the intense heat,

is accounted for by the theory that the intense downward pressure prevents fusion. Where, however, from any cause this pressure is relieved, the deep-seated portions become locally liquefied, and we have the volcano and its attendant phenomena. There is finally a third theory—that of the Rev. Osmund Fisher and others, who, holding that the view of a solid and cooling earth is insufficient to account for all the facts, advocate the hypothesis of a *thin viscous stratum, reposing on a solid interior, and covered by a solid crust*. The crust is solid because it is already cooled, the intermediate liquid stratum exists where the downward pressure is insufficient to prevent liquefaction, and the nucleus is kept solid by the excessive pressure at all the greater depths.

49. In all the foregoing theories, the original molten state and the slowly cooling condition of the globe are implied. The heat originally possessed by the earth is presumably being given off to outer space, and as the heated nucleus cools it contracts. The already cooled crust resting upon it sinks downwards towards the centre, and in the process becomes *wrinkled* up into alternate ridges and hollows. The wider ridges form the continents, and the broader hollows the ocean basins. The minor wrinkles give origin to mountain-ranges, and the minor depressions to seas and lakes. As the earth is continually parting with its heat, this crust movement must be equally continuous, but it is varied in its effects by local accidents and conditions. In one area the movement may be so gentle and gradual as not to be discernible till after the lapse of centuries, as in the *secular upheaval* of S. Scandinavia, or the *regional depressions* in the coral region of the Pacific. In another area the tension is suddenly relieved by a snap and fracture of the crust, and we have the awful visitation of the *earthquake*. Or the stresses generated in the bending and twisting crust may relieve the pressure below, and the liquefied material may make its way to the surface in the terrible eruption of the *volcano*.

#### VOLCANOES.

50. A typical *volcano* may be broadly described as a conical mountain with a pit-shaped opening (*the crater*) near the summit, which communicates with the deep-seated parts of the earth crust by a central pipe or funnel (*throat* or *vent*), and out of which are ejected stones, ashes, dust, and melted lavas. The mountain is composed wholly of these materials, which have gradually piled themselves around the vent.

With each eruption the volcano increases in height, and so long as the same pipe remains open, so long will the mountain retain its conical shape. Should a fresh orifice break out upon its flanks, however, a *parasitic volcano* will be formed,

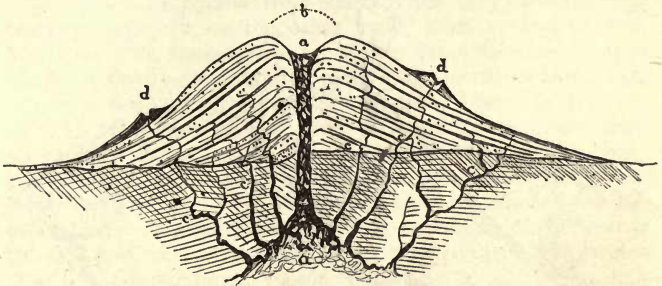


Fig. 18.—Showing structure of Volcano (Judd).  
a a, Throat or neck; b, Crater; c, Dykes and veins; d, Lateral or parasitic volcanoes.

which may eclipse its parent cone or destroy its symmetry. By a series of such parasitic cones, irregular volcanic piles of great height and breadth may be formed. Volcanoes may occur practically isolated, but they normally occur in extended lines, usually in the neighbourhood of the sea-coast. At the present day the shores of the Pacific Ocean afford the grandest development of active volcanoes. They extend in a fairly continuous line from Terra del Fuego, along the crests of the Andes, through Mexico and California to Mount St Elias and Alaska, attaining their culminating-point in Aconcagua (23,000 feet). From Mount St Elias they are continued in the Kuriles to Kamtchatka, and thence by Japan and the Philippines to Papua, New Caledonia, New Zealand, and the Antarctic continent, thus girdling the Pacific with a ring of fire. A second but connected line borders the north-east edge of the Indian Ocean, from Timor through Java and Sumatra to the shores of Further India. The rest are less intimately connected. The Atlantic chain (embracing those of Iceland, the Azores, and the Canaries), and those of the Mediterranean (Vesuvius, Etna, Stromboli, and Santorin), are the most familiar and best known. Such are the volcanoes still in action (*active volcanoes*); but *extinct* volcanoes occur in many other regions—those of Auvergne and the Eifel being familiar instances on the continent of Europe. Even in our own islands the extinct volcanoes of Mull, Skye, and Morven

still retain evidence of their original conical form,—while the Ochils, the Pentlands, the Arenigs, and other British ranges, are mere weathered remains of ancient volcanic sheets.

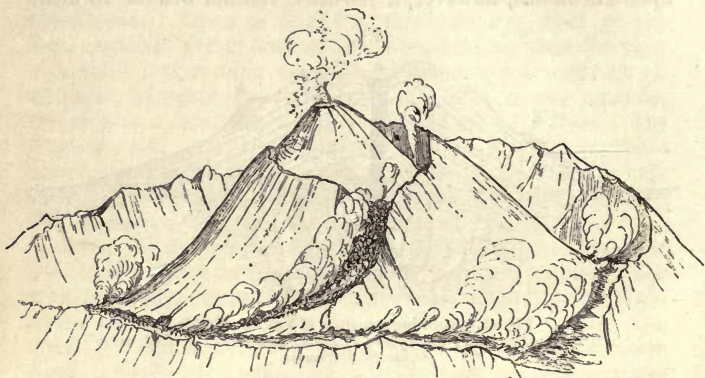


Fig. 19.—Showing conical form of Volcanoes (Scrope).

51. As a general rule the materials thrown out from a volcano are ejected with extraordinary violence. After premonitory shocks of earthquake, the floor of the crater is blown in fragments into the air by a sudden explosion of steam, which rises to a great height over the crater, and becomes condensed and falls as rain. This is succeeded by a discharge of rock fragments, ashes, and fine dust. The lava then gradually rises in the funnel, and finally pours out over the lip of the crater, or from lateral fissures, down the mountain-side. The chief *gaseous material* ejected from volcanoes is *steam*; carbonic acid and sulphurous acid also occur, but in insignificant quantities. Next in importance follow the *fragmental matters*,—fragments, bombs, lapilli, and dust. The *fragments* are torn off the throat of the volcano. The *bombs* and *lapilli* are masses of the lava forced off by the ascending current of steam; the larger lumps, revolving in the air, cool on the outside into rounded *bombs*; the finer fragments fall as angular *lapilli*. The finest particles of the exploded lava form the *volcanic dust*, which floats out in widely extended clouds around the volcano. This dust is of excessive fineness, and may travel for enormous distances. In the year 1835, the dust ejected from the volcano Coseguina, in Central America, hid the light of the sun over an area 70 miles in diameter, and

some of it was borne to Jamaica, a distance of 700 miles. The recent dust-clouds poured from Krakatōa, in the East Indies, particles from which were collected on the continent of Europe, afford even a more remarkable instance.

52. The *lava* poured from the volcano may be either extremely liquid, or, on the other hand, more or less viscous, moving in the former case rapidly to great distances, and in the latter slowly accumulating around the mouth of the crater. The lava flood which issued from Skaptar Jökull, in Iceland, in 1783, was 50 miles long, locally 15 miles broad, and filled up ravines from 500 to 600 feet in depth. The lowest layer of a lava-flow cools rapidly, and forms a volcanic glass (*obsidian*); the upper portion, which gives off clouds of steam, becomes ropy, vesicular, or *scoriaceous*, and cindery. Interiorly, the lava-flow consolidates into more or less compact rock, which usually shows abundant visible *crystals*.

53. The size of volcanoes varies from that of mere mounds to gigantic piles like Etna (87 miles in circumference and 10,800 feet high) and Aconcagua (23,000 feet in height). All the grander piles are more or less composite in structure, being made up of many lateral and parasitic volcanoes. When from any cause the earlier vent becomes closed, or the height of the pile grows too great to allow of the lava being forced to the crater, the volcanic agencies fracture the mountain from beneath, and the liquid lava forces its way into the fissures, and there consolidates. Such a mountain mass, when its internal structure is laid bare by denudation, shows a succession of alternate layers of incoherent ashes and vesicular lavas, cut through by more or less vertical radiating and projecting ribs of hard volcanic rock, known as *dykes*, from their wall-like appearance when seen at a distance. (See fig. 44.)

#### Geysers.

54. Intimately associated with volcanoes, we find the eruptive hot springs known as *Geysers* (Icelandic, *geyser*, a roarer). A geyser is a natural tube or opening, filled with superheated water, descending for some distance into the earth crust, and opening above into a *basin*-like depression in the ground. At periodical intervals the geyser explodes with startling violence, throwing up a jet of hot water to a height of more than a hundred feet, with the evolution of enormous quantities of steam. As the water cools it flows back into the tube, where it becomes again heated, again to be erupted

as before. The waters of many geysers deposit silica, forming basins and terraces of remarkable variety and beauty of form. Geysers occur also in regions where volcanic activity is decreasing,—the declining volcanic energy, which in earlier times manifested itself in explosions of dust and ashes, being now only sufficiently powerful to give rise to eruptions of hot water. Such is the case in the famous Yellowstone district of North America. The sudden eruption of the geyser appears to be mainly due to the fact that the temperature of the sides of the tube increases with the depth. The boiling-point of the more highly heated waters below is raised by the downward pressure of the cooler waters above. When finally the expansive force of the steam generated at great depths is sufficient to overcome this downward pressure, the whole of the contents of the tube are blown into the air with terrific violence.

## EARTHQUAKES.

55. Earthquakes, which are but expressions of the same subterranean forces that give origin to volcanoes, produce modification of the earth crust chiefly by *fracture*, *subsidence*, and *elevation*. Although destructive convulsions are comparatively rare, it is not unlikely that minor earthquakes are actually of daily occurrence, an average of as many as two a-day having been *recorded* between the years 1843 and 1873. The shock of an earthquake is usually heralded by a curious *subterranean noise*, which has been compared to distant thunder or the rumbling of waggons. This noise is succeeded by the *shock* itself, which is a rapid up-and-down movement of the ground, sometimes so violent that the buildings of entire cities are hurled to the ground, and their inhabitants buried in the ruins. If the earthquake takes place below or near the sea-level, the waters of the ocean are set in motion. Drawn back from the land for a time, and laying bare the sea-bed along the coast, they pile themselves up seaward in a mighty mound of water many feet in height, which sweeps back with frightful speed, and hurls itself over the shore-line far inland, carrying all before it and completing the awful work of destruction.

56. According to Mr Mallet and other students of earthquake phenomena, an earthquake has its *origin* (or *focus*) at some point within the earth crust, varying from 5 to 30 miles below the surface of the ground. From this focus

radiates in all directions a wave (or succession of waves), which traverses the earth crust with great rapidity. This wave reaches the surface first at a point (*the seismic vertical*), immediately above the "focus." Here the shock is consequently delivered *vertically* upwards. At distances farther and farther removed from this central point, the wave will of necessity reach the ground at a later and later period (see figure), and will emerge more and more *obliquely*. Thus the

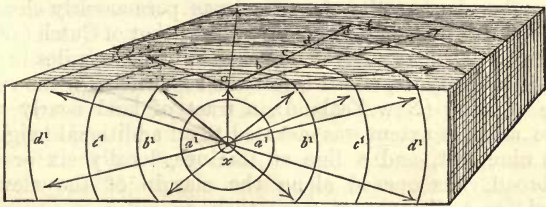


Fig. 20.—Section and perspective of Area shaken by Earthquake (Le Conte). *x*, Origin or centrum; *a*, Seismic vertical; *a' b' c' d'*, Section of spherical waves; *b c d e f*, Co-seismic circles.

places where the times of emergence are the same will form a series of circles (*co-seismic circles*) round the seismic vertical, from which the earth-wave will appear to have travelled outwards in all directions. As the overturning effect of the shock upon buildings is greatest in proportion to its obliquity, while the real intensity of the shock decreases and finally dies away altogether as we pass outward from the point of origin, the *region of greatest destruction* will also form a band surrounding, but some distance removed from the seismic vertical—*i.e.*, it will mark those places where the combined effects of the intensity and obliquity were at their maximum. The premonitory rumbling noise is the sound of the original shock or explosion travelling through the earth crust (11,000 feet a second),—the earth-wave itself travelling at a much smaller speed (800 to 1200 feet a second). The great sea-wave is due to the sudden elevation of the sea-bed above the earthquake focus. Its velocity varies with the depth of the water, but is always small compared with that of the earth-wave, and hence the delay in its appearance.

57. *The area affected by an earthquake is, generally speaking, in proportion to the intensity of the shock. The great earthquake of Lisbon (1755), in which 50,000 persons perished, was felt along the Atlantic shores from the Sahara to Iceland, and*

inland as far as eastern Switzerland. The earthquake of February 1835 (Chili) was felt over an area computed at 600,000 square miles. *The number and duration of the shocks* in an earthquake vary greatly. The earthquake of Caraccas, in which 10,000 persons were killed, lasted only thirty seconds; while the convulsions of Lisbon continued for fully five minutes. The *geological effects* wrought by the earthquake are mainly the *local elevation and depression of land*, and the formation of cracks and fissures in the ground. In the Chili earthquake of 1822, the shore-line was permanently elevated to a height of three or four feet; while in that of Cutch (1822), a district of country several thousands of square miles in area became suddenly depressed below the sea-level. In the earthquake of 1855 (New Zealand), a tract of land nearly 5000 square miles in extent was elevated to an additional height of about nine feet, and a line of fracture, locally six or nine feet broad, was opened along the margin of the elevated ground for a distance of more than 90 miles.

58. Of the *causes* of earthquakes little is known. They have been ascribed by some to the subterranean explosions of steam, a view to which their prevalence in volcanic districts lends great countenance. Others have regarded them as due to the earth-wave generated by a sudden snap—or fracture of a part of the earth crust in a state of great strain—an opinion grounded largely upon their frequency along coast-lines. At the present day the chief bands of earthquake disturbance range from Spain eastward through the basin of the Mediterranean to Central Asia, and thence round the shores of the Pacific,—zones practically coincident with those marked by the presence of active volcanoes.

#### SECULAR UPHEAVAL AND DEPRESSION.

59. We come, finally, to those gentle movements of the earth crust which take place so slowly that their effects are only discernible after the lapse of enormous periods of time. The evidences of these movements, however, are recognisable upon almost every shore-line. In one locality we discover ancient sea-beaches elevated far above the modern water-level. In another, old forest tracts are found deep below the present tide-marks. In a third, islands formerly covered by roaring breakers rise high and dry above the waves. In a fourth, the sea-marge creeps inland century after century, as the country is slowly depressed. As the quantity of water in the

ocean basin is always the same, and as that water is free to find its own natural level, the ocean level must be regarded as remaining constant and invariable. It is the level of the land which is changing, not the level of the sea. "*Stability of the sea, mobility of the land,*" is the expression of a paradoxical truth which lies at the very foundation of geology.

60. The proofs of *secular elevation* are abundant and striking. *Human erections*, once at the sea-line, like the ancient Greek docks of the coast of southern Crete, are now elevated far above tide-mark. North of Stockholm the grooves formerly cut by the pilots to mark the sea-level are now several inches above it, and the gradual *rise of the land* in Northern Sweden is estimated at  $2\frac{1}{2}$  feet in a century. In Central Sweden beds of *marine shells*, of species inhabiting the present seas, are met with at heights of from 100 to 200 feet above the sea-level, in Norway at 700 feet, and along the littoral tracts of South America at all elevations up to 1300 feet. In Britain we find testimony of elevation equally trenchant in the *raised beaches* of Scotland, which are met with at various heights between 25 and 200 feet. These are well-marked grooves or terraces cut by the ancient sea-waves along the former shore-lines of our island, and affording the clearest proof of their marine origin in their form, in their subsoil of sea-sand and fragments of sea-shells, and in their old sea-cliffs and caves.

61. The evidences of *secular depression* are naturally not so conspicuous at first sight, as the submerged shore-lines become buried from sight below the water-level. Here again, however, the testimony of *human erections* comes to our aid. In

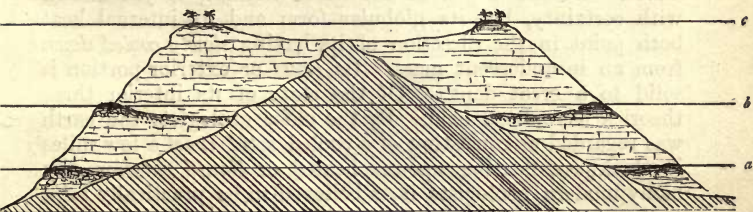


Fig. 21.—Ideal section illustrating Darwin's theory of the mode of formation of an Atoll. *a a*, Level of sea when reef was a *Fringing reef*; *b b*, Level of sea when reef was a *Barrier reef*; *c c*, Present level of sea—reef forming an Atoll.

South Sweden the ancient streets of some of the shore towns are now several feet below the sea-level. The west coast of Greenland is sinking so rapidly that the settlers have again

and again been forced to plant fresh boat-posts nearer and nearer the shore, the old posts becoming submerged below the rising waters. Around the coast of Cornwall and Devon *submerged forests* occur in several localities below tide level. But most remarkable of all is the evidence afforded by the phenomena of *coral-reefs*, described in par. 37, which, according to Darwin's theory, are demonstrative of the gradual depression of widespread tracts of the ocean floor itself.

#### RECAPITULATION.

62. Having discussed the mode in which the sub-aerial agents waste and remove the materials of our earth crust, we now turn to those *Subterranean Agents* whose province it is to repair this destruction, and to keep in habitable equilibrium the land and water surface of our globe. These agents are three in number—the *Volcano*, *Earthquake*, and *Secular Crust-movement*. These all appear to be due to the slow dissipation of the internal heat of the globe—the solid earth crust sinking in upon the cooling and contracting interior, here slowly in vast regional Undulations, there suddenly in the startling shock of the Earthquake, or with local fracture and emission of steam and heated material as in the Volcano.

63. The proofs of the *Internal Heat* of the globe are afforded by the evidence derived from the *rise of temperature* as we descend into the earth crust ( $1^{\circ}$  Fahr. for every 40 to 60 feet of descent); the existence of *hot springs* in non-volcanic regions; and lastly, from the presence of *volcanoes* themselves. Of the *origin* of the globe nothing is yet known with certainty, but its globular form and its internal heat both point in the direction of its having *slowly cooled down* from an incandescent mass. Its *crust* or exterior portion is solid to a great depth. Of the state of its interior three theories have been held. By the older geologists the earth was regarded as consisting of a cooled *solid crust* a few miles in thickness, floating upon a heated or *liquid interior*; by many modern geologists it is believed to be practically *solid to the centre*; and by some to consist of a solid crust and a solid nucleus, having between them a *film of melted material*, where the superincumbent pressure is insufficient to counteract the effect of the intense internal heat.

64. The most striking manifestation of the subterraneous forces is seen in the *Volcano*. Typically, a volcano is a conical mountain having a hollow at its summit (*crater*), from which

a tube or pipe (*throat*) passes down the centre of the mountain into the heated parts of the earth crust below, and out of which are ejected steam, fragmentary materials, and melted lava, the mountain itself consisting of the solid matters erupted from below and piled in sloping layers around the crater. The *fragmentary materials* are lapilli, volcanic blocks and bombs, and fine ashes. The *lavas* consist of melted rock, originally containing large proportions of steam, and when cooled, forming crystalline rock, glassy obsidian, and scoriæ and pumice. The lavas and ashes are usually arranged in layers sloping outwards from the sides of the throat, and the volcanoes are usually pierced in all directions by cracks filled with consolidated liquid material, which hardens in wall-like *dykes*. Volcanoes are distinguished as *active*, *dormant*, or *extinct*, according as they are in frequent eruption, merely emit occasional clouds of steam, or have wholly lost their eruptive force. In regions where volcanic activity is declining we find the eruptive hot springs known as *geysers*.

65. The *Earthquake* acts geologically by causing fracture, elevation, and subsidence. It is usually heralded by a *subterranean noise*, which is followed by the earthquake shock or *earth-wave*, and this in maritime districts by a much later *sea-wave*. The earth-wave originates from the *focus* of the earthquake, and reaches the surface at the *seismic vertical*, from which it travels over the ground in concentric circles (*co-seismic circles*). Its *origin* is obscure, and has been referred to subterranean explosions of steam or to sudden fractures of the earth crust.

66. Less striking to the ordinary mind, but far more important from the geological point of view than the earthquake and volcano, is the long-continued *Crust-movement* of upheaval or depression. The evidences of *upheaval* are abundant in the form of *raised beaches*, in the presence of *marine shells* at great heights inland, in the gradual and measured rise of the shore-line, in the elevation of buildings originally at the sea-level to heights far above it. The proofs of *depression* are less conspicuous but equally convincing, in the existence of *submerged forests*, in *coral-reefs* and atolls, and in the submergence of towns and other *human erections*.

## PART II.—PETROLOGICAL GEOLOGY.

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### CHAPTER IV.

#### GENERAL ARRANGEMENT, STRUCTURE, AND CLASSIFICATION OF THE STRATIFIED MATERIALS CONSTITUTING THE CRUST OF THE GLOBE.

67. As we have already indicated, the external portion or crust of the globe, accessible to human research, is composed of a variety of more or less solid substances known as *rocks*. No matter whether in the form of soft and yielding clay, of loose sand and gravel, of beds of chalk and sandstone, or of masses of granite—all are termed by geologists *rocks* and *rock-formations*. And the reason is obvious: the sand and gravel of the sea-shore are but the comminuted fragments of the cliffs above, and have necessarily the same composition; while the mud and clay of the deeper waters are merely still finer comminutions of the same rocky material. Of such substances is the crust of the earth composed, and in one form or other we pass through them wherever we go beneath the surface—whether tunnelling through the hills, or sinking coal-mines in the level valleys. How these rocks are arranged, and of what they are composed, are the subjects of our present inquiry.

#### STRATIFIED OR SEDIMENTARY ARRANGEMENT.

68. Judging from the operations of the modifying causes explained in the preceding chapter, one would naturally infer that all matter deposited as sediment from water would be

arranged in layers along the bottom. Fine mud and clay readily arrange themselves in this manner, and sand and gravel are also spread out in layers or beds more or less regular. In course of time a series of beds will thus be formed, lying one above another in somewhat parallel order, thicker, it may be, at one place than at another, but still preserving a marked horizontality, and showing distinctly their lines of separation or deposit. Thus the miscellaneous *débris* (a convenient French term for all waste or worn material, wreck, or rubbish) borne down by a river will arrange itself in such layers along the bottom of a lake—the shingle and gravel falling first to the bottom, next the finer sand, and lastly, the



Fig. 22.—*Stratified Arrangement of Sediments.*

impalpable mud or clay, as represented in the preceding diagram. In course of time a series of layers will be formed, one above another, not perfectly parallel, like the leaves of a book, but still spread out in a flat or horizontal manner. One cannot look at the face of a quarry, or pass through a railway-cutting, without observing how very generally the rocks are arranged in *beds* and layers. These layers are technically known as *strata* (plural of *stratum*). Hence all rocks arranged in such layers—that is, arising from deposition or sediment in water—are termed *aqueous*, *sedimentary*, or *stratified*. In applying these terms the student will perceive that *aqueous* refers to the chief agency by which such rocks have been produced, *sedimentary* to the mode in which they have been formed, and *stratified* to the way in which they are arranged.

#### IGNEOUS OR UNSTRATIFIED ARRANGEMENT.

69. On the other hand, when we examine the rocky matter originally intruded in a melted state into fissures of the earth crust, or ejected above its surface in the form of lava and ashes from volcanoes, we observe no such lines of deposit, and no such horizontality of arrangement. In general, they break through the stratified rocks, or spread over them in

mountain-masses of no determinate form—here appearing as walls, filling up rents and chasms, there rising up in huge conical hills, or flowing irregularly over the surface in streams of lava. When such rocks are quarried or cut through, they do not present a succession of layers or strata, but appear in *amorphous* masses—that is, masses of no regular or determinate form (Gr. *a*, without, and *morphé*, form or shape). Thus, in connection with the stratified rocks, they present something like the annexed appearance,—A A A being stratified or sedimentary rocks lying bed above bed, and B B being the unstratified, rising up through the former in massive and irregular forms.



Fig. 23.—*Stratified and Unstratified Rocks.*

Referring to their origin, the amorphous rocks are spoken of as *igneous*, and to the way in which they have been produced, *eruptive*; while in contradistinction to the stratified rocks, they are termed the *unstratified*. We have thus in the crust of the globe two great divisions of rocks, the STRATIFIED and UNSTRATIFIED; and, as we shall afterwards see, to one or other of these divisions do all rock-formations belong, however much broken up, displaced, and contorted, or how great soever the changes that may have taken place in their mineral texture and composition.

#### RELATIVE POSITIONS OF STRATIFIED ROCKS.

70. Although originally laid down as incoherent sediments below the level of the sea, we now find the stratified rocks usually hard and stony,—forming sheets of *sandstones*, *coals*, *shales*, or *limestones*, as the case may be (see figs. 24 and 25),—upheaved far above the sea-level, and in many cases folded, crushed, and broken in a variety of ways. This has been effected by what is known as *lateral pressure*, *crust-creep*, due possibly to the gradual contraction and wrinkling together of parts of the earth crust. By this agency the wide-spreading sheets of horizontal strata have been bent into *folds* or undulations of all dimensions. In some areas the breadth of these crust-folds (*flexures*) may be many hundreds of miles, and the strata may remain approximately

horizontal; in others, especially on the borders of our continents, the crust-wrinkling is so intense, that the strata are bent up into mighty ridges, like those of the Alps and Appalachians. By this agency also the strata themselves have been locally crushed, dislocated, and broken in a variety of ways. Finally, since their upheaval above the sea-level, the upper edges of these folds, and most of the higher strata, have been worn away by rain and rivers and other agents of denudation, and carried out to sea. In this way it follows that the present surface of the land is in reality formed of the weathered edges of these upheaved and folded strata; and it is by their careful study and investigation that the geologist is enabled to study the composition and structure of the rocks and rock-formations, and express their arrangement in his geological memoirs, sections, and maps.

71. Such rocks as still remain level are termed by the

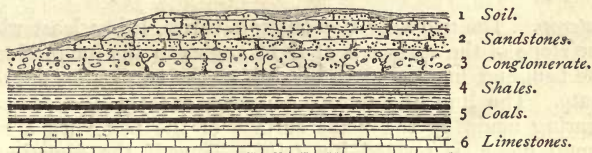


Fig. 24.—Horizontal Strata.

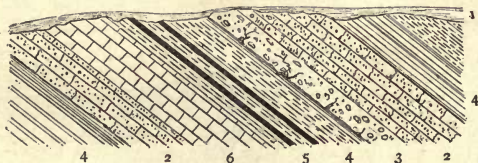


Fig. 25.—Inclined Strata.—1, Soil; 2, Sandstones; 3, Conglomerate; 4, Shales; 5, Coals; 6, Limestones.

geologist *horizontal*. Those which are tilted at various angles are said to be *inclined*. In mountain-ranges, &c., it usually happens that the strata are inclined, or even perpendicular; while in a few extreme cases the strata are pushed beyond the vertical, and are then said to be overturned or *inverted*. The amount of inclination of a stratum, or the angle which its plane makes with that of the horizon, is known as its *dip*; and strata are said to dip at angles of ten, twenty, or thirty degrees, as the case may be. The angle of dip is

measured by an instrument called a *clinometer* (*klino*, I slope; *metron*, a measure). The *thickness* of a group of parallel strata can of course be easily estimated from its dip.

72. The space occupied by the denuded surface of a stratum upon the surface of the ground is termed its *basset edge* or



Fig. 26.—Showing Outcrop of Beds in a mountain district.

*outcrop*. The *width* of the outcrop varies, being least where the slope of the surface is at right angles to the inclination of the bed, and increasing in breadth as the two angles approximate. The line of outcrop, or, more exactly, the compass-bearing made by the plane surface of the bed with a horizontal plane, is termed its *strike*. Thus if the direction of the outcrop of the plane surface of an inclined bed on level

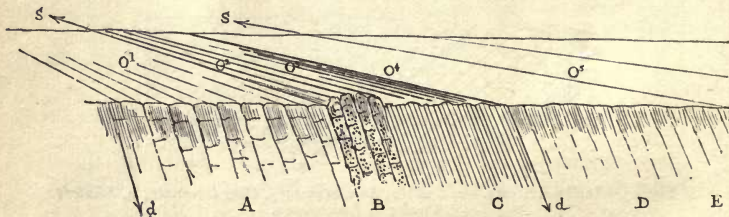


Fig. 27.—Section and perspective showing Dip, Strike, and Outcrop of Beds. *d d*, Dip; *s s*, Strike; *O¹-O⁵*, Outcrops of the rock-formations, *A* to *E*.

ground be from north to south, it is said to *strike* in that direction. The direction of dip is always at *right angles* to the *direction of strike*; a bed striking from south to north is either vertical or must dip to the east or west. Where the ground is level the outcrop and strike will coincide, and if the strata are not bent will form a straight line. Where the beds are folded or dislocated, the outcrop will be sinuous or disjointed.

73. Where the strata dip in opposite directions from the crest of a fold, they are said to form a saddle or *anticline*, and the line of the crest of the arch is called an *anticlinal axis*



Fig. 28.—Showing effects of Folding and Denudation of Rocks.  $a^1-a^3$ , Contorted rocks;  $b^1-b^2$ , Inclined strata;  $c^1-c^6$ , Folded strata;  $d^1-d^4$ , Inliers;  $e^1-e^5$ , Outliers;  $o-f$ , Over-fault.

(*anti*, opposite). Where, on the other hand, they dip inwards towards the trough or hollow of the fold, they form what is termed a *syncline* (Gr. *syn*, together). Where the surface of the ground is level, and the strata are not folded, the outcrops of the strata will form a series of parallel bands. Where the strata are bent into irregular loops and folds, the outcrops will be winding or tortuous, and will vary much in width. A plan showing the form of the outcrops of the formations on



Fig. 29.—Geological Map.  $M N$ ,  $O P$ , Lines of section. See fig. 30.

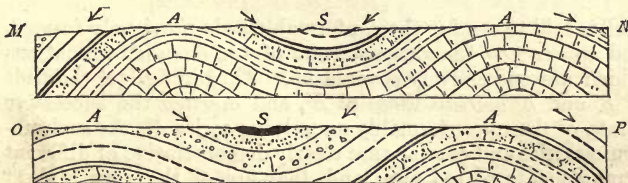


Fig. 30.—Geological Sections.  $A A$ , Anticlines;  $S S$ , Synclines.

the ground is known as a *geological map*. An exposure showing their vertical arrangement in a cliff or quarry face is called

a *natural geological section*; while a figure showing their disposition as inferred from observation or calculation is known as an *ideal section*.

When strata which have been long exposed to denudation (see *A*, fig. 31) are again depressed below the sea-level, they become covered by a new set of sediments, which fill up

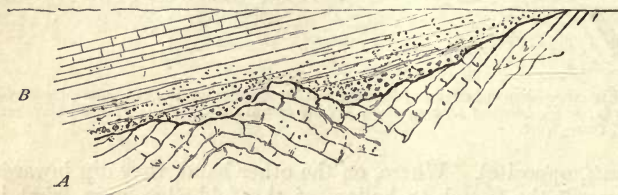


Fig. 31.—Unconformability.

their depressions (*B*, fig. 31), and form an overlying series parallel among themselves, resting on the eroded edges of the older series, and usually sloping at a different angle. Such series are said to be unconformable to each other, and the appearance is termed an *unconformability*. If the sea-bed sinks in such a manner that each new stratum of the upper series extends farther landward than the previous stratum,

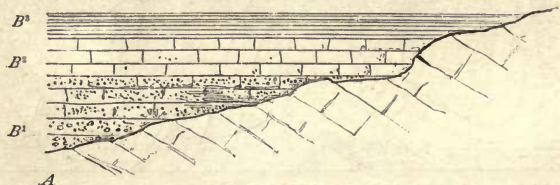


Fig. 32.—Overlap.

each is said to *overlap* the conformable beds previously formed, and to *overstep* the various strata of the denuded formations which are successively covered up. Thus in fig. 32, the beds of  $B^2$  and  $B^3$  *overlap* those of  $B^1$ , and *overstep* the successive strata of the unconformably underlying series *A*. As such unconformities and overlaps are clearly demonstrative of different arrangements of sea and land, they are of the very highest importance in historical geology.

74. The effects wrought by denudation upon strata and rock-formations are seen in the production of all the varieties of scenery and soil, as well as in certain geological pheno-

mena of special importance, for which certain technical terms have been coined. Where strata terminate abruptly in a bold bluff edge or cliff, they are said to form an *escarpment* (Fr. *escarpe*, steep). Isolated patches or masses of strata which rise up from below other formations of later age are known as *inliers*; while *outliers* are patches of rock surrounded on all sides by strata of greater antiquity. In all cases of this kind the connection of the rocks composing these isolated patches with those of the main mass is traced and confirmed either by the mineral similarity and succession of its strata, or by the identity of their fossils with those contained in the main formation.

#### JOINTING IN STRATIFIED ROCKS.

75. Most rocks are divided by transverse cracks into blocks of various shapes and sizes. These cracks are known as

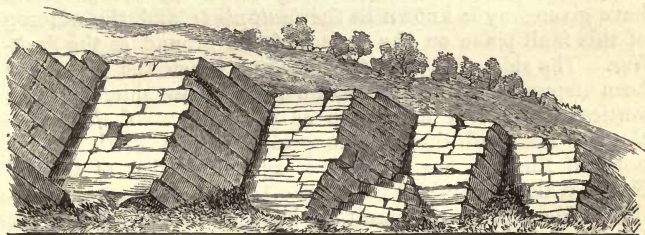


Fig. 33.—*Jointed Structure of Rocks.*

*joints*, and in sedimentary rocks these joints traverse, as a rule, only a single bed or stratum, fresh joints occurring in the strata above and below. There are usually two distinct sets of joints in each stratum; one set running with the strike of the rocks, *strike joints*, and another with their dip, *dip joints*. By these two sets of joints, which usually make a large angle, or may be at right angles with one another, each bed is divided into a layer of subquadrangular blocks, like a course of masonry. The work of the quarryman and coal-miner consists in taking advantage of these natural fissures, the existence of these joints permitting of the removal of the stone in solid shapely blocks. Jointing in stratified rocks appears to be due mainly to the contraction of the rock in drying, but in some cases it seems to have been caused by the compression and twisting of the beds during elevation and folding.

## FAULTS AND DISLOCATIONS.

76. Of far greater geological importance than these joints or shrinkage - cracks are the great crust - fissures, which have their origin in earth-movements, and are known as *faults or dislocations*. Unlike joints, which are simply cross-fissures in a single stratum, these great fault-fissures sometimes extend through many formations to a great depth in the earth crust, and are prolonged for enormous distances, occasionally for hundreds of miles. In a joint, the stratum is merely fissured and broken, but the broken edges are not displaced. In a fault, on the other hand, the formations on one side have slipped up or down along the plane of the fissure, and their fractured edges, originally continuous, are now removed for great distances from each other, sometimes for many thousands of feet.

77. The plane of fracture along which the broken strata have given way is known as the *fault-plane*, and the outcrop of this fault-plane on the surface of the ground as the *fault-line*. The side of the fault-plane along which the beds have been depressed is known as the down-throw side, and the vertical amount of depression as the amount of the *down-throw*. The fault-line of the great Pennine Fault of the north of England has a length of 130 miles, that of Bala in North Wales a length of 66 miles. On the northern or down-throw side of this latter fault the beds have been depressed at least 3000 feet below their original position. As a general rule, the strata upon the opposite sides of a fault have been worn to the same level by denudation, so that there is no visible evidence of the existence of the fault upon the ground; but in some instances, as in the case of the great faults of

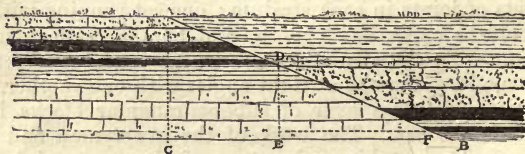


Fig. 34.—Normal or Ordinary Fault. AB, Fault-plane; angle CAB, Hade of fault; DE, Down-throw; EF, Lateral shift.

Colorado, the up-throw side of the fault is marked by steep slopes, rising several thousands of feet above the level of the country where the corresponding beds have been depressed.

78. In a rock-section in a mine or quarry face, a fault is recognised as a line of fissure along which beds originally continuous have been separated by a distinct interval. The fault-plane is usually more or less inclined. The amount of this inclination is known as the *hade* of the fault; and, unlike the dip of strata, is *measured from the vertical*. The *throw* of the fault is the vertical distance through which the beds have been depressed, and is measured by the vertical distance between the level of a broken extremity of a bed and that of the corresponding bed on the opposite side of the fault-plane. The horizontal distance through which the broken ends of the beds have been removed is termed the *shift* of the fault. As a general rule, the beds have *slipped down* the inclined plane of the fault—in other words, *faults hade to the down-throw*. There are cases, however, especially

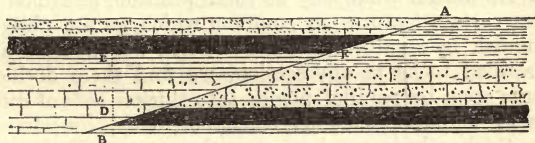


Fig. 35.—Inverted Fault or Over-fault. BA, Fault-plane or thrust-plane; DE, Uplift; EF, Overthrust.

in mountain regions subjected to intense lateral pressure, where the beds have been thrust up the fault-plane. In the former case the fault is termed a *normal fault*; in the latter it is said to be *inverted fault* or *over-fault*; and the plane of dislocation as the *gliding-plane* or *thrust-plane*.

79. The surface of the fault-plane is usually smooth and highly polished (*slicken-sided*) by the movement of the strata. Occasionally, however, the plane is irregular, presenting hollows filled with smashed material (*fault rock*) or various



Fig. 36.—“Step” Faults.

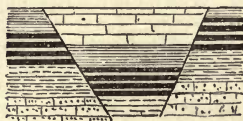


Fig. 37.—“Trough” Fault.

crystallised minerals deposited by infiltrating waters (*mineral veins*). The fault-line in normal faults may be either a single and more or less straight line throughout (*simple fault*),

or may branch again and again (*compound fault*). Sometimes the depression of the beds is effected by a series of parallel faults of small throw (*step faults*), or by a pair of faults hading towards each other (*trough fault*). As respects direction, they may be either *strike* faults, *dip* faults, or *oblique* faults. *Over-faults*, or the inverted faults of mountain regions, are usually compound and inosculating (*loop faults*), enclosing lenticular patches of dislocated rocks, and the outcrop of the thrust-plane, in proportion as the hade approximates nearer and nearer to the horizontal, becomes more and more sinuous, resembling the outcrop of the basement bed of an unconformable series.

#### INTERNAL CHARACTERS OF STRATIFIED ROCKS.

80. No matter what may be their position, stratified rocks possess certain features in common which we are obliged to distinguish by significant terms. When we examine a mass of stratified rocks in any section, we find them divided, as we have seen, by parallel planes into thicker *beds* of different kinds of material, such as sandstone, clay, limestone, &c. These thicker beds are known as the *strata*. Each stratum again may be divided up into several *layers*, *seams*, or even fine *laminæ* or leaves of the same kind of material, but differing slightly in colour, composition, and the like. The laminæ are usually straight, and parallel with the surfaces of the main beds, but they often show the oblique or curvilinear arrangement indicative of their deposition in shallow or rapidly moving waters (*current-bedded* or *false-bedded* rocks). The



Fig. 38.—*Strata of Sandstone, showing False Bedding or Oblique Lamination.*

plane of separation marking the upper and lower surface of each bed is known as the *plane of bedding* or stratification. The surfaces of the bedding planes are sometimes covered

with *ripple marks*, or show *sun-cracks*, *rain-prints*, the foot-marks of the animals, and the like, but this is very rarely the case. They are usually more or less smooth and regular. As a general rule, the coarser strata only separate along the main lines of stratification and jointing, but the finer-grained strata are commonly fissile throughout parallel to the bedding. Occasionally, however, some of the fine-grained layers—clays and limestones—show the curious structure known as *concretionary*. In these the iron, silica, or calcareous matter of the stratum has collected into ball-like masses, often round the relics of some plant or animal; and these concretions, from their peculiar composition, being of a much harder nature than the main mass of the rock, project like layers of included balls or pebbles. In certain magnesian limestones the concretions are of most extraordinary shapes, and have been fancifully compared to cannon-balls, piles of shot, and bunches of grapes.

#### MINERAL COMPOSITION OF STRATIFIED ROCKS.

81. The composition of the sedimentary rocks constituting the crust of the globe may be viewed in two ways, either *chemically* or *mineralogically*. To the chemist every substance in nature is resolvable into certain primary *elements*; and of such elements upwards of sixty have been discovered—some gaseous, some liquid, some solid, some metallic, and others non-metallic. In examining a piece of marble, for example, the chemist resolves it into carbonic acid and lime; or, more minutely, into oxygen, carbon, and a metallic element called calcium. It is enough for the mineralogist, on the other hand, to know that it is composed essentially of crystalline *calcite*. But not only has the geologist to describe it petrographically as a limestone, pure or impure, soft or compact, earthy or crystalline, as the case may be; but he has to note more especially its position and mode of occurrence, with what rocks it is associated, what fossils are embedded in it, and from these and other data he endeavours to arrive at the conditions under which it was formed, and the aspect of the world at the period of its formation. In drawing such conclusions, he is greatly aided by the deductions of chemistry and mineralogy; hence the importance of these sciences to the practical geologist.

82. For elementary purposes it is enough to know the more familiar chemical substances and their leading compounds,

such as the *gases*—oxygen, hydrogen, nitrogen, and chlorine; the *metals*—iron, gold, silver, copper, lead, zinc, tin, mercury, manganese, arsenic, and antimony; the *metallic bases*—sodium, potassium, aluminium, calcium, and magnesium (which, when united with oxygen, form the *earths* and *alkalies*—soda, potash, alumina or pure clay, lime, and magnesia); and the *non-metallic* bodies—silicon (*silex*, flint), carbon, sulphur, and phosphorus. Of these, the most important, from the geological point of view, are (a) *oxygen*, which is a constituent of all rocks, forming about a half of the earth crust by weight; (b) *silicon*, one-fourth of the earth crust by weight, and which in combination with oxygen forms silica or quartz, and this in its further combinations with certain bases forms the *silicates*—the chief ingredients of igneous rocks; (c) *aluminium*, whose oxide alumina is the basis of clay; (d) *calcium*, whose oxide *lime*, in combination with carbonic acid, forms limestone; and (e) *carbon*, the element most important in organic structures, limestone, and coal.

#### CLASSIFICATION OF STRATIFIED ROCKS.

83. The stratified rocks fall naturally into two main classes: (1) *Fragmental rocks*, or those formed by the action of water from the broken and rounded fragments worn off the solid land; and (2) *Organic rocks*, or those formed mainly by the agency of animal and vegetable life. Fragmental rocks are divided into *arenaceous* or sand-rocks, *argillaceous* or clay-rocks; while the organic rocks are divided into *calcareous* rocks, formed by the agency of animals, and *carbonaceous* rocks, formed by the agency of plants.

##### *Arenaceous* (Lat. *arena*, sand) or *Siliceous* (*silex*, flint) *Rocks*.

These, as their name implies, are formed of gravel or sand, and are distinguished according to the relative degree of coarseness of the materials of which they are composed. In their unconsolidated state they are known as *shingle*, composed of large rounded pebbles; *gravel*, of a mixture of angular and water-worn fragments; and *sand*, minute rounded particles of quartz derived from the attrition of volcanic and siliceous rocks. The consolidated rock formed of gravel is known as *conglomerate* or *pudding-stone*, when the fragments are large and rounded; when more or less angular, as *breccia* (from an Italian word signifying a crumb or fragment). *Sandstone* is the general name applied to rocks formed of sand, and hardened by pressure, or by some natural cementing material such as silica (*siliceous sandstones*), carbonate of lime (*calcareous sandstones*), or oxide of iron (*ferruginous sandstones*). When sandstone is capable of being easily

dressed by the hammer for building purposes it is denominated *freestone*, and when capable of being split up into large sheets for paving, &c., it is known as *flagstone*. Coarser sandstones whose particles are sharp and angular are distinguished as *grits*. Sandstones whose grains are cemented by infiltrated silica into a dense rock breaking with a conchoidal fracture are known as *quartzites*. A compact greenish-grey grit or flagstone, usually containing much felspathic matter, and very common among the older geological formations, is known as *Greywackè*.

#### *Argillaceous or Clay Rocks (Lat. argilla, clay).*

The unconsolidated forms of this group are known as *mud* and *silt*, terms employed familiarly for the impalpable matter which settles in quiet waters, and *clay*, which differs from mud mainly in its great purity and compactness, and in being more or less tough and plastic. Consolidated clay is known as *mudstone* when devoid of lamination, and as *shale* when splitting freely along the planes of bedding. The term *slate* is applied to those argillaceous rocks which have been hardened and cleaved by earth-pressure, and which split easily along a new set of planes usually distinct from those of the original bedding.

#### *Calcareous Rocks.*

*Limestone* is the general term for all rocks the basis of which is carbonate of lime. The softer and earthier-looking varieties, formed mainly by the agency of foraminifera, are distinguished as *chalk*, and those deposited by calcareous springs as *travertine* or *calc-sinter*. The term *magnesian limestone* is applied to those limestones containing a large proportion of magnesia. *Marl* is a loose appellation for all friable compounds of lime and clay. The compact and mottled varieties of limestone are popularly known as *marbles*; but, strictly speaking, this term is confined geologically to those crystalline varieties which have been altered or metamorphosed.

#### *Carbonaceous Rocks.*

Of these, by far the most important is *coal*, which may be defined as mineralised vegetable matter, containing less or more of earthy impurities. In burning, the organic or vegetable matter is consumed, and the earthy or inorganic matter left behind as ashes. Coal occurs in many varieties, of which the chief are: (1) *Lignite* or brown coal, usually of geologically recent formation, and in which the woody structure is still apparent; (2) *ordinary coal*, wholly mineralised, jet black, and burning with a clear flame; and (3) *anthracite*, a dense crystalline variety, burning without either smoke or flame.

Such are the chief kinds of sedimentary rocks that are of importance in the architecture of the earth crust; but there are in addition a few mineral compounds of like origin which have an especial geologic or economic importance, and which fall to be noticed in this place. The most important of these are:—

1. *Siliceous.*

(a) *Quartz*.—This is the name given to pure silica when in an amorphous form; *rock-crystal* is the name given to pure transparent varieties; and coloured varieties are known as *amethyst*, *topaz*, &c. The crystalline form of quartz is a six-sided prism terminated by a six-sided pyramid. *Flint* is the name used for impure nodules of siliceous matter, abundantly found in chalk strata. *Chert* is the name given to the impure siliceous nodules and layers found in many other rocks. The silica of which flint and chert have been formed appears to be derived from siliceous sponges and the like. *Chalcedony*, *opal*, and *agate-sinter* are siliceous masses produced by the infiltration of water holding silica in solution. *Jasper* (red), *Blood-stone* (green, spotted with red), and *Lydian stone* (black), are names applied to certain compact varieties of siliceous rocks usually showing smooth and conchoidal fractures. *Siliceous sinter* is the name given to the compact flinty material deposited by geysers and the like.

2. *Calcareous.*

The crystalline form of carbonate of lime is known as *calc-spar* or *calcite*, and occurs typically in veins as a white mineral of a rhombohedral form; the transparent variety is called *Iceland spar*. *Gypsum* is a sulphate of lime, and, when calcined, forms the well-known plaster-of-Paris. Transparent crystals of gypsum are distinguished as *selenite*. *Dolomite* (after the geologist Dolomieu) is the term applied to crystalline varieties of magnesian limestone.

*Saline or Salt-like Compounds.*

*Common Salt* (chloride of sodium) is too well known to require description. It is found in thick incrustations on many sea-coasts, and on the sites of dried-up lakes. It occurs locally in the solid crust as *rock-salt*, and is held in solution by all sea-water and brine-springs.

*Nitrates of Soda and Potash* occur as incrustations and efflorescences in many plains, marshes, and lakes in hot countries. These salts are known as *natron*, *trona*, &c.

*Alum* (sulphate of alumina and potash), though chiefly extracted from certain shales and schists, is also found in nature in the saline or crystallised state.

*Borax* (soda and boracic acid, borate of soda) is another saline product discharged by the thermal springs of some volcanic districts.

*Metallic.*

*The Metals* are either found *native*—that is, in a pure state—or combined with mineral matter in the state of *ores*. Gold, platinum, silver, copper, and a few others, are often found native in pellets, nuggets, and thread-like branches; but the majority of the metals are chiefly found as *ores*—that is, as oxides, sulphides, carbonates, &c. Lead, for instance, is found in sparry veins as a sulphuret (*galena*), carbonate, phosphate, &c. Copper, zinc, tin,

and manganese are generally found in a similar way. The metals almost invariably occur in *mineral veins*. Iron, however, is an exception, and is found in concretionary and stratiform layers in our coal-fields as a carbonate, *clay ironstone*, *black-band*, &c., or in bogs (*bog-iron-ore*) and in lakes, &c. Like the other metals, however, it also occurs in veins and masses, as *hæmatite*, *magnetite*, &c.

#### *Argillaceous.*

The term *fire-clay* is employed to distinguish those varieties of clay which, from the absence of alkaline earths (potash and soda), resist the action of heat. *Fuller's earth* (a hydrous silicate of alumina) is employed in the fulling and scouring of greasy linens. *Kaolin* or china-clay is pure white clay derived from the decomposition of the felspar in granite, &c.

#### *Carbonaceous.*

The black decomposed vegetable matter found in bogs, &c., in temperate regions, is known as *peat*. Graphite or *plumbago* (the substance of which writing-pencils are made) is an almost pure carbon, found in veins or disseminated among the older rocks. *Oil-shales* are shales containing a large proportion of hydro-carbons. When this oil is distilled by natural processes, it gives rise to *petroleum* or rock-oil, *naphtha*, *asphaltum*, and the like.

### RECAPITULATION.

84. The object of the foregoing chapter has been to describe the arrangement, structure, and classification of the *sedimentary* rocks. Wherever a section of the earth crust has been exposed, whether naturally in cliffs or ravines, or artificially in quarries or mines, the rocks are found to be arranged either in layers or in indeterminate masses. Those arranged in layers have been evidently formed by the agency of water; those in shapeless masses, by the agency of volcanoes and the like. The stratified rocks, originally laid down below the sea-level as incoherent sediments, have been consolidated and upheaved above the sea-level by *lateral pressure*, and bent into *folds and flexures*, and more or less *denuded and broken*. Their positions are indicated by such terms as *horizontal*, *inclined*, *vertical*, or *inverted*; by *anticlinal*, *synclinal*, *bent*, or *contorted*. Their dip or inclination is measured by the *clinometer* by reference to the horizon, and their *strike* or bearing by the *compass*. Their denuded edges are known as *outcrops*, and a plan of these outcrops is termed a *geological map*, and a figure of their disposition below the surface a *geological section*. Where a new set of beds has been laid down upon the edges of an older series, the appearance is denominated an *uncon-*

*formity* or *overlap*, as the case may be. Isolated exposures of older strata are known as *inliers*, and patches newer than the beds surrounding them as *outliers*.

85. The transverse cracks in rocks are termed *joints*, which are distinguished according to their direction as *strike-joints*, *dip-joints*, &c. The grander fractures of the earth crust are called *faults* or *dislocations*; the plane of fracture being known as the *fault-plane*, and the outcrop of the fracture as the *fault-line*. In *normal* faults the *hade* (which is measured from the vertical) is always to the *downtthrow*; in *inverted* faults the beds have been pushed up the fault-plane. The *varieties of faults* are known as simple, compound, dip faults, strike faults, step faults, and loop faults.

86. The main layers of aqueous rocks are known to the geologist as *strata* or *beds*, the upper and lower surfaces as the *bedding-planes*. Each bed may be divided into *laminæ*, and its structure may be *incoherent*, *fissile*, *compact*, or *concretionary*.

87. The sedimentary rocks are classified according to the composition and the relative coarseness of the materials of which they are composed. The *FRAGMENTAL rocks* are divided into *arenaceous* or siliceous rocks, including conglomerate, breccias, sandstones, flagstones, and grits; the *argillaceous* rocks into clays, mudstones, shales, and slates. The *ORGANIC rocks*, again, are arranged into *calcareous* rocks, including limestone, chalk, and marl; and *carbonaceous* rocks, including lignites, coals, and anthracite. But all these varieties shade more or less the one into the other. Thus we may have an argillaceous sandstone, a siliceous limestone, and a calcareous shale; or, still more minutely, an argillo-calcareous sandstone and a calcareo-arenaceous shale. To aid the student in distinguishing these varieties, he should early begin to collect rock-specimens for himself, these specimens showing at once the weathered surface as well as the fresh fracture. He should examine with his magnifying-glass their intimate texture and mineral composition, and compare them, where he has any doubt, with the specimens in some authentic collection, to ascertain their usual names, localities, and industrial applications. A few facts thoroughly realised are worth scores imperfectly comprehended and partially understood.

## CHAPTER V.

### THE IGNEOUS ROCKS.

#### THEIR COMPOSITION, STRUCTURE, AND CLASSIFICATION.

88. PRECISELY as in the case of the stratified or aqueous rocks, we find igneous or volcanic rocks at all stages of the earth's development. From the earliest geological times to the present, volcanoes have poured out clouds of steam and ashes, and floods of melted lava, while the subterranean forces have injected masses of liquefied material into chasms and fissures deep within the earth crust, there to cool into solid rock. As the margins of continental areas are those marked at the present time by the prevalence of igneous activity, so, too, they appear to have been in the ages of the past. Where the sea-floor became locally upheaved, the volcanoes became locally extinct, to break out afresh along the margins of the new-made land. In this way almost every great region of the earth crust has had its period of volcanoes, which have left evidences of their former presence in its rocky framework. The volcano of the present day, active, dormant, or extinct, is recognisable by its characteristic conical form, and its composition of alternate layers of lava and ashes; while these lavas and ashes themselves bear, in their own internal structures and textures, the evidences of their original liquid or fragmentary condition. But it is vastly different with many of the volcanoes of the past. Worn away foot by foot by the action of the elements, they are now the mere shadows of their former selves, and, in extreme cases, a few insignificant layers of lava and ashes are all that remain to attest their former size and grandeur. Often the entire volcano has disappeared as such, and its place is marked only by a network of dykes, or by the vast masses of igneous mate-

rial that fill the subterranean cavities from which the volcano was fed. Nor have the volcanic piles themselves been the only objects which have suffered from the changes brought about in the long periods of geological time. Their very lavas and ashes themselves have often lost their original features. Infiltrating waters, here removing the soluble constituents, there replacing them by others, have effected such vital and widespread chemical changes that it is sometimes impossible to say what were the original characters of some of the more ancient volcanic materials. The study of the igneous rocks is consequently enshrouded in a cloud of difficulties from which the study of the stratified rocks is comparatively free, and much is yet to be learnt before all their phenomena are properly understood.

89. The solid products of modern volcanoes are, as we have seen, fragmentary ashes and lapilli, and floods of melted rock. The ashes and lapilli are blown into the air, and fall down upon the land or into the sea, where they become more or less stratified in layers; and, except in composition, agree precisely with the stratified aqueous rocks. The floods of melted rock, however, whether poured over the surface or injected into subterranean fissures, have peculiar features of their own, totally distinct from those of the aqueous sediments, but typical, more or less, of all volcanic rocks whatever. The ashes and lapilli are merely the shattered fragments of this originally liquefied material, and show, in all their minuter characters, the same structure and composition. A typical aqueous rock is composed of more or less rounded *fragments* of other rocks, *sorted by water*, and derived from the washing away of the *superficial* parts of the earth crust. A typical igneous rock has *cooled down* from a state of *fusion* or semi-fusion, caused by *heat*, and has been derived from *below* the earth crust. The internal texture of an aqueous rock depends upon the relative coarseness of the *fragments* of which it is composed, due to their longer or shorter exposure to the action of the elements. The internal texture of an igneous rock depends upon the relative coarseness of its *crystals*, due to the special conditions under which the rock cooled down from a state of fusion.

#### TEXTURES OF THE IGNEOUS ROCKS.

90. In the liquid, or more or less fused state, in which the igneous material is brought up from below, its chemical con-

stituents are in a complete state of intermixture. If such a mass be cooled slowly, such of the chemical ingredients as have special affinities for each other combine as the heat decreases, and form crystalline bodies, of various forms and dimensions, —from exceedingly minute *crystallites* and *microliths*, to well-defined *crystals*, varying from microscopic size to an inch or more in length. If the period of cooling be sufficiently prolonged, the whole mass becomes transformed into an aggregate of large crystals (*granitic texture*), as in the case of

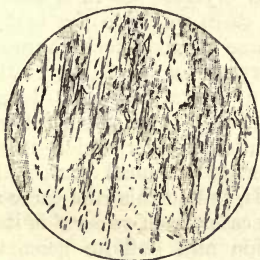


Fig. 39.

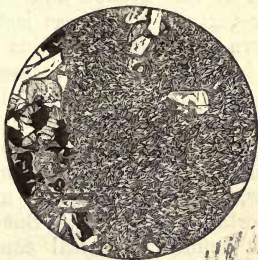


Fig. 40.

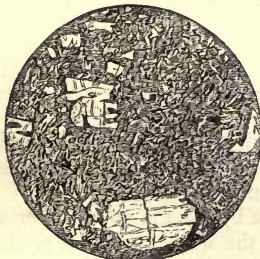


Fig. 41.



Fig. 42.

Figures illustrating the various Textures of Igneous Rocks (Judd).

Fig. 39.—Obsidian—*Vitreous texture*, showing *fluxion structure*, the *crystallites* being arranged in lines of flow.

Fig. 40.—Dolerite—*Trachytic texture* of base.

Fig. 41.—Felsite—*Porphyritic texture*.

Fig. 42.—Granite—*Granitic texture*.

granite or syenite. If, however, the cooling be sudden, no crystals can be formed, and the result is a volcanic *glass* (*vitreous texture*), like tachylite or obsidian. Between these two extremes there may be every gradation of texture, according as the action of cooling was relatively fast or slow.

Sometimes only one or two mineral species may have had opportunity to develop crystals, and we may find the resultant rock composed of larger crystals set in a granular or microlithic (the so-called *trachytic*) or glassy (*vitreous*) base. Or it may happen that a mass of igneous material cooling at great depths, in which large crystals have begun to develop themselves, may again be set in motion and forced to the surface, where its magma will cool with much greater rapidity. In this event we shall have a rock formed of larger and more or less broken and corroded crystals, set in a base of finer texture. In these last two cases we have the texture known as *porphyritic*. But all these igneous rocks agree in the fact that they are formed of crystals or crystalline matter. The special minerals which have crystallised out, depend upon the general chemical composition of the original liquid material or *magma*, or the conditions under which it was formed. Rocks of the same average chemical composition show, as a rule, the same minerals, but to this rule there are important exceptions. But in all cases, each *mineral* is itself of a definite chemical composition and definite geometric form, and each possesses individual characteristics which enable it to be identified and named with certainty by the chemist and mineralogist.

#### MINERALS OF THE IGNEOUS ROCKS.

91. Igneous rocks are composed of the so-called chemical *acid*, silica, and the *bases*, alumina, potash, soda, magnesia, and lime, together with a certain proportion of *iron*. Of these chemical constituents silica is by far the most important, varying from 40 to 80 per cent of the whole. It is sometimes met with alone in the form of quartz, but it usually occurs in combination with one or more of the *bases*, giving rise to the great group of the *silicates*, which form the vast majority of the minerals of which the igneous rocks are composed. This large proportion of silica in the igneous rocks furnishes us with a means of arranging them broadly according to their chemical composition—rocks with more than 65 per cent of silica being classed as *Acid Rocks*, those containing from 45 to 55 per cent as *Basic Rocks*, while those having an intermediate proportion are known as *Intermediate Rocks*.

92. The minerals out of which the crystalline igneous rocks are built up may also be naturally grouped, according to their

chemical composition, into *Silica proper*, the *Silicates*, and the *Oxides of Iron*.

**MINERALS COMPOSED OF SILICA.**—The chief mineral composed of silica is *quartz*. This occurs sometimes in the form of complete crystals, but is usually met with in the shape of rounded grains or irregular crystalline patches. When in crystals it is recognisable at once by its glassy texture and lustre, and its crystalline form, consisting of a hexagonal prism, terminated at both ends by a hexagonal pyramid. In most igneous rocks, however, the prismatic faces are very rarely developed.

**MINERALS COMPOSED OF SILICATES.**—There are two main groups of these—viz., those in which *silicate of alumina* is the chief constituent, and those in which *silicate of magnesia* is most important. The silicates of alumina include the feldspars, and mica; the silicates of magnesia embrace the minerals, hornblende, augite, enstatite, olivine, and serpentine.

*Silicates of Alumina, &c.* :—

**The Feldspars.**—The *Feldspars* constitute the most important of all the minerals that make up the igneous rocks, being present in large proportion in all except in the extreme (ultra) basic rocks. They are recognised by their platy structure, their glossy faces, and comparative hardness. There are two chief types—*Orthoclase* (Gr. *orthos*, straight; *clao*, I cleave), so called because it cleaves in two directions at right angles to each other; and *Plagioclase* (Gr. *plagios*, oblique), in which the chief cleavages are not at right angles. *Orthoclase* is a potash feldspar (a silicate of alumina and potash). A glassy variety is known as *sanidine*. Under *plagioclase* are grouped several varieties agreeing essentially in crystalline form, but differing largely in chemical composition: (a) *albite* (Lat. *albus*, white), or soda feldspar; (b) *oligoclase* (Gr. *oligos*, little), a soda-lime feldspar; *labradorite* (after Labrador), a lime-soda feldspar; and *anorthite* (Gr. *anorthos*, oblique), a lime feldspar. Crystals of the plagioclastic feldspars show a distinct appearance of striation upon one of their cleavage faces, wanting in orthoclase.

**The Micæ.**—Like the feldspars, these differ much in chemical composition. They agree, however, most remarkably in their chief structural characters, being all formed of thin, elastic, and more or less transparent laminae. The two chief varieties are *muscovite* (or Moscow glass), potash mica, and *biotite* (after Prof. Biot), or magnesia mica. The colour of the latter is usually *black* or blackish-green, that of the former *white*.

*Silicates of Magnesia, &c.*—The minerals composed mainly of silicates of magnesia are all green or black in colour, varying from pale-green to greenish-black. The more important species are:—

*Hornblende* or *amphibole* (Ger. *horn*, from its toughness, and *blende*, a mineral), a dark-green or black mineral, occurring in short oblique prisms, blades, or fibres (*asbestos*), or long needles (*actinolite*).

*Augite* (Gr. *auge*, lustre), a dark-green mineral allied in chemical composition to hornblende; differing, however, in crystalline form,

common in short squat crystals in the basic rocks. An altered form with a beautiful metalloidal lustre is known as *diallage* (Gr. *diallagè*, difference).

*Hypersthene* (Gr. *hyper*, above, and *sthenos*, strength), a mineral allied to augite in composition, but differing in crystalline form. The varieties containing a large proportion of iron compose hypersthene proper; those with an intermediate proportion are known as *bronzite*, and those with little or no iron as *enstatite*. Hypersthene is a common ingredient in many volcanic rocks, such as those of the Andes, Java, Sumatra, &c.

*Olivine* (from its colour), a dark-green mineral occurring in small crystals or glassy blebs in most basic and ultra-basic rocks. It is very susceptible of alteration, and finally passes into serpentine.

*Serpentine* (from its mottled serpent-like appearance), an olive-green mineral forming a well-known rock which is often streaked and mottled with red. Rocks originally containing much olivine are sometimes wholly transformed into *serpentine rock*.

*Chlorite* (Gr. *chloros*, green), a dark-green flaky mineral occurring in scales, tufts, or fibrous aggregations. It is often due to the alteration of hornblende, augite, or other allied minerals.

**OXIDES OF IRON.**—Iron occurs more or less in a state of combination in hypersthene, hornblende, and other magnesian silicates. It is also met with as an oxide in a crystalline form. The two chief varieties are (a) *magnetite*, which occurs as small octahedrons in the basic and altered rocks; and (b) *titanic iron*, or *ilmenite*, occurring disseminated as iron-black crystals or grains.

In addition to the foregoing, several minerals are known which are wanting in Britain, but which form important constituents of some of the igneous rocks of the Continent. The most important are the *felspathoids*—of which the chief are, *leucite* (Gr. *leucos*, white) and *nepheline* (Gr. *nephelè*, a cloud). The last named, however, has been met with in one locality in the Scilly Islands.

#### CLASSIFICATION OF THE IGNEOUS ROCKS.

93. The igneous rocks differ among themselves, as we have seen, (a) in *chemical composition*, (b) in the *minerals* of which they are formed, (c) in their internal *structure*, (d) in their relative *position* in the earth crust, and (e) in their geological *age*. It is clear that these distinctions are of a gradually diminishing order of value; and the most *natural classification* of the igneous rocks will be that in which all these distinctions are employed in the order of their relative importance. Such are the classifications which are gradually being

developed at the present day. By the earlier geologists, geological age and mineralogical composition were the chief distinctions employed in classification, and naturally so. They discovered that the most coarsely crystalline rocks, such as granite and its allies, which occur necessarily at great depths in the earth crust, either rose up from below the deepest sedimentary strata, or were associated with the oldest geological formations. Hence they naturally classed them as *Plutonic* (or *Granitic*), and regarded them as the deepest and oldest of igneous rocks. Again, the finer-grained lavas and intrusive sheets of the older geological formations, denuded, disguised, and chemically altered in the enormous lapse of time since their original formation, were naturally erroneously looked upon as being quite different in character from modern volcanic rocks, and were grouped together as *Trappean*, from the circumstance that they generally occur in prominent ridges and terraces (Swedish, *trappa*, a flight of stairs) among the older fossiliferous strata. The modern igneous rocks, and those occurring in the most recent geological formation and still retaining their original characters unmodified, were grouped together as *Volcanic*. Traces of this older nomenclature still survive even in our most recent schemes of classification, and the terms have still a certain value if we continually bear in mind their origin and limitation.

94. The internal *textures* of igneous rocks which result from different conditions of cooling, &c., have been already noticed. There are, however, a few *structures* with which it will be necessary for the student to be acquainted. Thus the upper parts of a lava-flow are usually filled with hollow cavities formed in the more or less fused mass by the expansive force of steam. These are known as *vesicles*, and the structure as *scoriaceous* or *vesicular*. As the mass spreads out around, or becomes deformed by the stretching and dragging out of the cooling material in the direction of flow, these vesicular layers become elongated, and are, in extreme cases, pulled out into a light vesicular and stringy mass known as *pumice*. Ancient vesicular and pumiceous volcanic rocks, which have been long buried beneath later accumulations, frequently have their vesicles filled up by a deposit of carbonate of lime or silica introduced by infiltrating waters, each vesicle becoming filled up by a solid almond-like inclusion. This structure is known as the *amygdaloidal* structure (Gr. *amygdalon*, an almond).

95. Bearing the foregoing facts in mind, the student will have no difficulty in comprehending the following scheme of

classification, in which the *crystalline* or *massive* igneous rocks are arranged as nearly as may be in the order of their natural relationships as at present understood.

### Division A.—ACID ROCKS.

SECTION I.—*Acid Rocks* proper (silica, 65 to 80 per cent). Characteristic minerals, *Orthoclase*, *Mica*, and *free Quartz*.

#### (a) *Plutonic* or *Coarse-Grained Varieties*.

*Granites* (Lat. *granum*, a grain), typically formed of crystals of *orthoclase*, *mica*, and *free quartz*: a coarsely crystalline aggregate of crystals of the above-named minerals. Many varieties are known, varying in texture, or differing slightly in mineralogical composition. The coarsest-grained varieties are sometimes known as *pegmatites* or *giant-granites*, and the finer-grained as *micro-granites* and *elvanites*. A variety in which the quartz and felspar are inter-crystallised in a sort of mosaic, and the crystals of mica so arranged that they resemble Hebrew characters, is known as *graphic granite*. The mineralogical varieties are named after the mineral which may more or less replace the characteristic mica, such as *hornblendic* granite, *augite* granite, and the like. Granite sometimes becomes *porphyritic* by the development of large orthoclase crystals, as in the beautiful granite of Shap.

#### (b) *Volcanic forms*, or *Acid Lavas* and *Intrusive Rocks*.

The lavas having the same general chemical and mineralogical constitution as granite, form the group of the *rhyolites* and *liparites*. The former (from Gr. *rheo*, I flow) are named from their beautifully striped and banded *flow-structure*, like that of furnace slags; the latter name (from the *Lipari Islands*) is applied to those varieties in which the flow-structure is not so apparent. Volcanic glasses are abundant in this section, such as *obsidian*, with a vitreous, and *pitchstone*, with a resinous lustre. The less compact (trachytic) varieties are designated *quartz trachytes*, when the sanidine is unaltered. The ancient forms of liparite and quartz trachyte, &c., occurring in the older rocks, in which the sanidine has taken on the characters of orthoclase, are designated *quartz felsites* (Ger. *fels*, a rock).

### Division B.—INTERMEDIATE ROCKS.

SECTION II.—*Sub-Acid Rocks* (silica, 60 to 65 per cent). Characteristic minerals, *Orthoclase* and *Hornblende*.

The *Plutonic*, *granitoid*, or *coarse-grained* forms of this section are denominated *syenite* (a name originally applied to the rock now known as syenitic granite or hornblendic granite, so called after the locality of Syene, in Upper Egypt, whence it was obtained for ornamental or architectural purposes by the ancients). Typical syenite differs from granite in the absence of quartz, and in the replacement of mica by hornblende; but some varieties of syenite contain a little quartz (*quartz syenite*), others mica (*mica syenite* or *minette*), others augite (*augite syenite*), &c.

The *Volcanic* or *Trachytoid* forms of this section constitute the group of the *trachytes* proper (quartzless trachytes), (from Gr. *trachys*, rough—in allusion to the rough harsh feel of their fractured surface, due to their internal microlithic texture). The trachytes are named according to their most conspicuous mineral, such as *sanidine trachytes*, *hornblende trachytes*, &c. Glassy forms are rare. The more or less altered trachytes, in which the sanidine has gone over to orthoclase, are placed with the felsites (*hornblende felsite*, *mica felsite*, &c.)

SECTION III.—*Sub-Basic Rocks* (silica, 55 to 60 per cent). Characteristic minerals, *Plagioclase* and *Hornblende*.

The *Granitoid varieties* of this section are grouped collectively under the term *diorite* (Gr. *dioros*, distinct), which differs from syenite mineralogically in the substitution of plagioclase for orthoclase. The chief varieties are *mica diorite* (or *kersantite*) and *quartz diorite*.

The *volcanic* or *trachytic* forms of this section compose the group of the *andesites* (from the *Andes* mountains, where they are comparatively abundant). They are darker in colour than the typical trachytes. Sanidine is replaced by some plagioclasic felspar. They resemble the trachytes, however, in texture and general microscopic character. Some of the varieties are *hornblende*—*mica*, *hypersthene*, *enstatite*, *augite*, and *quartz*—*andesites*. The last named is sometimes called *dacite*. The more or less altered forms of andesite occurring in the older geological formations are usually described under the name of *porphyrite*.

#### Division C.—BASIC ROCKS.

SECTION IV.—*Basic Rocks* proper (silica, 45 to 55 per cent). Characteristic minerals, *Augite*, *Plagioclase*, with a little *Magnetite*, and often *Olivine*.

The *Plutonic* or *granitoid* forms of this large section constitute the group of the *gabbros* (from an Italian word applied to rocks of similar character), very coarse aggregates of plagioclase and augite—the latter, however, usually in the form of *diallage*. Of these there are some peculiar varieties, such as *olivine gabbro* and *troctolite*, the latter of which differs from the former in the general absence of augite.

The *Volcanic* and *intrusive* forms of this section, including the more finely-grained or trachytic varieties, are extremely abundant and widely spread. Those in which the matrix is visibly crystalline are known as *dolerites*; those in which the matrix is microlithic and compact, as *basalts*. A glassy form of the latter varieties, occasionally found forming the selvages of dykes, is known as *tachylite*. The olivine and augite of these rocks are more or less altered by chemical agencies in the older varieties, and these altered dolerites and basalts have received distinct names, the former being termed *diabases* and the latter *melaphyres*. The term *greenstone* is often employed as a convenient field-name for those more or less

altered basic and sub-basic rocks with doleritic texture which occur as dykes among the geological formations.

SECTION V.—*Ultra-Basic Rocks* (containing less than 45 per cent of silica).  
Characteristic mineral, *Olivine*.

These rocks, which are comparatively rare in all countries, are coarsely crystalline, and contain in large proportion the mineral olivine (peridot). Hence they are known collectively as the *peridotites*. They approximate in composition to some of the meteorites. Augite and enstatite occur in them occasionally, and also iron and nickel. The commonest British example is *picrite* (olivine and augite, or olivine and hornblende). Many of the British *serpentes* are altered peridotites.

Such are the chief varieties of the Igneous rocks of the British Isles. On the continent of Europe, and elsewhere, several additional varieties occur. Of these, the most abundant are the nepheline- and leucite-basalts and dolerites, in which the felspar is replaced by nepheline and leucite. When a certain amount of felspar is also present, we have the group of the *phonolites*, so called from their dense platy structure, which causes them to ring under a blow of the hammer (Gr. *phonos*, sound). Phonolite has been met with in one locality (Wolf Rock, Scilly) in the British Isles.

#### RECAPITULATION.

96. In the preceding chapter we have concentrated our attention upon the constitution and classification of the Igneous rocks. Less accessible in Britain than the Sedimentary rocks, destitute of fossils, irregular in position, and altered and disguised by chemical agencies during the long ages of the past, their study has been a matter of more than ordinary difficulty, and we are only just beginning to arrive at a proper explanation of their structures, and at a natural system of classification.

97. The products of modern volcanoes are gaseous, fragmentary, and fused or liquid. The gaseous products are carried away by atmospheric agents; the fragmentary products are spread out in vast sheets, and their study approximates to that of the ordinary sedimentary rocks; but the fused, or more or less liquid materials have a special and typical character of their own, originating *massive* (as contradistinguished to bedded), *crystalline* or *vitreous* (as opposed to fragmentary), and piles or sheets of *original* (as distinguished from derived) material. The internal texture of the crystal-

line rock is dependent upon its rate of cooling, and may be *glassy (vitreous), microlithic, finely crystalline, coarsely crystalline, or even porphyritic*; and its structure *compact, vesicular, pumiceous, or, when altered, amygdaloidal*.

98. All igneous rocks are composed, more or less, of silica, and the bases (alumina, potash, soda, and lime) with iron, and, in extreme instances, nickel; and are classified into *Acid, Sub-acid, Sub-basic, Basic, and Ultra-basic*, according to the relative proportion of silica they contain. The minerals developed within them vary generally according to the chemical composition of the rock as a whole, each class having its own characteristic group of minerals. The chief are *Silica*, or free quartz; the *Silicates*, including the silicates of alumina and the silicates of magnesia; and finally, the *Oxides of iron*. The silicates of alumina constitute the important group of the *Felspars*, of which two species, *Orthoclase* and *Plagioclase*, form the chief types—the chief variety of the former being *Sanidine*, and the more important varieties of the latter, *Oligoclase, Labradorite, Albite, and Anorthite*. The silicates of alumina include the *Hornblendes* or *Amphiboles*, the *Augites* or *Pyroxenes* (with *Diallage*), the *Enstatites* or *Hypersthene*s, *Olivine*, and its altered product *Serpentine*. The oxides of iron are chiefly *Magnetite* and *Ilmenite*.

99. The most natural classification of the Igneous rocks is that in which *chemical composition, mineralogical constitution, texture, mode of occurrence and amount of alteration*, have each their proper value assigned them. As the igneous rocks erupted at all stages of the earth's history appear to have been generally the same, the old names, *Plutonic, Trappean, and Volcanic*, serve us merely as convenient field-terms: the first being used to distinguish the coarse-grained, deep-seated igneous rocks; the second, the more or less altered, erupted, or intruded igneous rocks of the geological formations; and the third, those rocks of all ages which have been clearly erupted at the surface. In the most recent schemes of classification we find the Igneous rocks arranged primarily into *Acid, Intermediate, and Basic* rocks. The *Acid Rocks* proper have *Granite* as the *Plutonic* or coarse-grained type, *Rhyolite* or *Quartz trachyte* as the *Volcanic* type, with the glassy *Obsidian*. The intrusive and altered types form the group of the *Quartz felsites*. The *Intermediate* rocks have *Hornblende* as their typical mineral: one subdivision (the *Sub-acid* rocks) having this mineral in association with *Orthoclase*, a second (*Sub-basic*) in association with *Plagio-*

*clase.* The coarse- and medium-grained forms of the sub-acid rocks constitute the *Syenites*. The Volcanic forms are the *Trachytes*, altered forms of which are known as *Quartzless felsites*. The Plutonic forms of the sub-basic rocks are the *Diorites* (the *Greenstones*, in part, of the field geologist); and the Volcanic forms, if unaltered, are known as *Andesites*—if altered, as *Porphyrites*. Next follow the typical *Basic Rocks*, in which *Augite*, *Plagioclase*, and a little oxide of iron are the normal constituents, with or without the mineral *Olivine*. In this group we have the coarse-grained *Gabbros*, the medium-grained *Dolerites*, and the still finer-grained *Basalts*—the altered forms of the second being grouped as *Diabases* and *Greenstones*, and those of the latter as *Melaphyres*. Finally, we have the remarkable section of the *Ultra-basic* rocks or *Peridotites*, of which the best-known British example is known as *Picrite*. The altered forms of the *Peridotites* are *Serpentines*.

## CHAPTER VI.

THE IGNEOUS ROCKS (*Continued*).

## THEIR ARRANGEMENT IN THE EARTH CRUST.

100. The Igneous rocks of the present day may be roughly arranged in two groups—those which are *ejected* at the surface and those which are *intruded* into fissures below the surface. So long as a volcano continues to pour forth lava and ashes, thus repairing the continuous waste due to denudation, the intruded rocks will remain buried from sight; but when the volcano declines in energy and becomes extinct, the looser material will be gradually carried off, and the basal portions of the volcanic pile, formed of the older ashes and lavas pierced by intrusive sheets and dykes, will become exposed to view. But the two classes of rocks will still be easily distinguished—the *ejected* lavas by their vesicular and fluxial structures, and the ashes by their stratified fragmentary character; while the *intruded* rocks will be recognised by their position in filled-up fissures, and by their more or less compactly crystalline texture, due to their comparatively slow rate of cooling under great pressure below a thick cover of superincumbent material. In the case of the ejected lavas and ashes, such as fall into neighbouring seas or lakes will become mixed and interstratified with ordinary sediments, the layers of which can be arranged and classified, and their geological age ascertained. In other words, the *ejected* igneous rocks will be *Contemporaneous* (of the same age), or *interstratified* with the sedimentary deposits with which they occur. On the other hand, the *intruded* rocks must necessarily be of later age than the rocks into whose fissures they have been injected. Hence they are classed as intrusive or *Subsequent*. Between the intru-

sive rocks that form the dykes of our modern volcanoes and those igneous masses which have been injected into fissures at great depths in the earth crust, and have become bared to sight only after the lapse of countless generations, there is every gradation both in position and texture ; while between the beautifully symmetrical forms of some of our modern volcanoes, through the more or less degraded extinct volcanoes of Europe and the ruined piles of western Scotland, down to the fragmentary sheets of more or less altered lavas and ashes which are all that often remain to us of some of the volcanoes of the earlier geological formations, we have a similar unbroken gradation. The old geological terms plutonic and volcanic, misleading when supposed to indicate geological age, still retain their meaning when expressive of relative position in the earth crust. The geologist of the present day is thus enabled to distinguish the two kinds of igneous rocks by striking and significant tests—classing the *ejected* rocks of all ages as *volcanic*, *interstratified*, or *Contemporaneous*, and the *injected* rocks as *plutonic*, *intrusive*, or *Subsequent*.

#### CONTEMPORANEOUS IGNEOUS ROCKS.

101. The volcanic or contemporaneous *igneous rocks* of all ages, like those of the present, have been either the *crystalline lavas* or the *fragmentary* ashes and lapilli, &c. The former radiate from the mouth of the crater in sheets, thickest usually near their point of origin, and dying away gradually as they pass outwards from the base of the volcanic piles. The ashes not only occur in thick sheets lapping round the flanks of the mountain itself, but their finer materials are scattered far and wide into the waters, mixing more or less with sedimentary matter, and forming what are called *tuffs*. The throat or *neck* of the crater, as the volcano becomes extinct, becomes filled up either with the fragmentary blocks, bombs, and ashy material of the final eruption, forming what is called *agglomerate*, or with the cooled material of the final lava flow. Such ancient filled-up volcanic *necks*, in part surrounded by the ruins of old volcanic piles, occur in Fifeshire and elsewhere, as in Largo Law, and in the well-known example of Arthur's Seat, Edinburgh. More frequently, however, the entire volcano has disappeared, the neck is represented merely by a large circular or elliptical shaft, bored originally more or less vertically through the earth crust, and filled with volcanic breccia or a variety of crystalline rock.

The most remarkable examples of *extinct volcanoes* in Europe occur in the districts of Auvergne, central France. The conical forms of the original piles, their central craters, beds of ashes, and sheets of consolidated lava, still remain more or less perfectly preserved. In Britain the best preserved

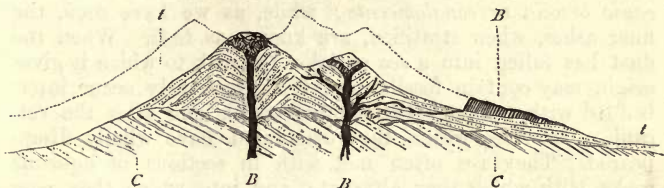


Fig. 43.—Section of the Volcanic Necks, &c., of Largo Law, Fife (A. Geikie). C C, Carboniferous rocks; B, Basalt, filling "Necks" and forming Lateral Veins (Dykes) and Sheets; t t, Tuffs.

volcanic piles are those of the district of Morven (Argyleshire), of Fife (Largo Law, &c.), and the basin of the Forth (Berwick Law, Arthur's Seat, &c.) In other cases the old volcanoes are represented by filled-up *necks*, from which radiate alternate sheets of lava and tuff, or solely by the neck itself. Generally, however, while no trace of the volcanoes themselves is discernible, their effects are exhibited in vast accumulations of volcanic material, piled up sheet above sheet, as in the igneous rocks of the Lake District, the Pentlands, and the Ochils.

102. A modern *coulée* or *lava flow* has a scoriaceous upper and under surface, and the vesicles are elongated in the line of flow. This fact enables us to identify an *interbedded* lava sheet at a glance, and to distinguish it from a *subsequent* sheet of intrusive rock. These vesicles are often filled up by a solid deposit from infiltrating waters, the amygdaloids formed in this way often yielding agates or zeolites. Lavas of acid type are more or less viscid and slaggy, flowing for a short distance only from the vent, and building up steep-sided volcanoes. Lavas of basic type, on the other hand, are extremely liquid, and flow for enormous distances. The steep ranges of Snowdon and other mountains in North Wales are largely made up of sheets of acidic rocks (felsite porphyry); while the low-lying regions of Morven and Mull are formed of enormous outpourings of basalt. The island of Skye is covered, almost from end to end, by layers of basalt, and the whole of the county of Antrim by outflows of the same basic

material. By some, however, the enormous sheets of these regions are believed to have been due not to true volcanic eruptions, but to *fissure-eruptions*, the material welling quietly to the surface through fissures in the earth crust, like those filled by our great basaltic dykes.

The coarser materials ejected from volcanoes form a *volcanic breccia* or *conglomerate*; while, as we have seen, the finer ashes, when stratified, are known as *tuffs*. When the dust has fallen into a sea or lake, the rock to which it gives origin may contain fossils, and tuffs frequently occur interbedded with ordinary sedimentary rocks, long after the volcanic piles from which they originated have wholly disappeared. They are often met with in sections of aqueous rocks, with which they alternate, and into which they pass by insensible gradations. Their varieties are named after the special type of lava from which the dust was derived, such as *felsite tuffs*, *andesite tuffs*, *basalt tuffs*, and the like.

The most important volcanic rocks of Britain are the rhyolitic lavas and ashes of Shropshire and Charnwood, the felsites of N. Wales and the Lake District, the andesites, porphyrites, and tuffs of the Sidlaws, Ochils, and Pentlands, and the basaltic rocks of the basin of the Forth, Argyle, and the Hebrides.

#### INTRUSIVE IGNEOUS ROCKS.

103. Coming next to the intrusive igneous masses, we find them classified according to the form and position of the fissure in which they have consolidated, into *necks*, *veins*, *dykes*, *sheets*, *laccolites*, and *bosses*. Volcanic necks have been already sufficiently described. Veins and dykes are names given to what are very closely related phenomena. By *intrusive veins* the geologist understands the narrow bands and strings of igneous rock filling up the irregular and minor fissures and cracks running out from the sides of the greater fissures. By a *dyke* is meant the wall-like mass of rock filling up a *vertical* fissure. These dykes differ from veins not only in their size, but also in the parallelism of their sides, usually standing up like vast walls. They vary in thickness from a few inches to 60 or 70 feet, and in length from a few feet to many scores of miles. The Cleveland dyke of the north of England has a length of 60 miles, and others in the south of Scotland have an extent probably greater than this. In those cases where the igneous material of the dyke is more easily weathered

than the rock into which it has been intruded, the dyke may be represented by a ditch-like hollow. Veins and dykes force their way through the rocks more or less at right angles to the stratification of the rocks. A *sheet* is a mass of igneous

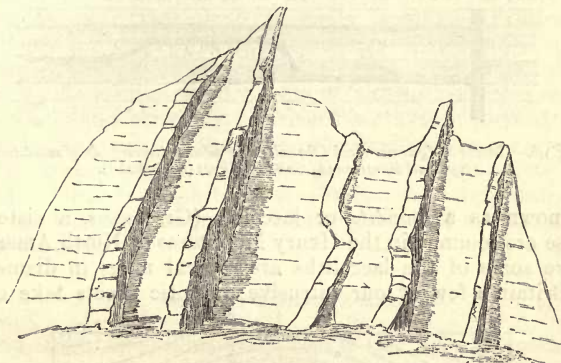


Fig. 44.—*Basaltic Dykes, Val de Bove, Etna (Abich).*

rock which has made its way along the bedding plane between two successive strata, forcing them apart, and consolidating in this position. At first sight it has the appearance of a contemporaneous lava flow, but it can be distinguished



Fig. 45.—*Granitic Veins (v v) traversing Gneiss at Cape Wrath (M'Culloch).*

by noting that (1) it bakes and alters the beds *both* above and below; (2) its upper and lower layers are not scoriaceous; and (3) when followed for some distance, it will be found to cut across the bedding, and to catch up fragments of the underlying and overlying rocks. Such sheets are abundant among the basaltic rocks of central Scotland, the

Hebrides, and elsewhere. Sometimes the igneous material of an intrusive sheet has forced up the overlying strata into a vast arch or anticlinal, and consolidated in the intervening space as a dome-like mass of crystalline rock. Such a mass



Fig. 46.—*Sheets of Igneous Rock (Basalt) intruded between beds of sandstone, clay, and limestone (Island of Skye) (after Judd).*

is known as a *laccolite* or *laccolith* (Gr. *laccos*, a cistern). These are common in the Henry Mountains of North America, where some of the laccoliths are several miles in diameter. In Britain a few of our intrusive doleritic sheets take on a

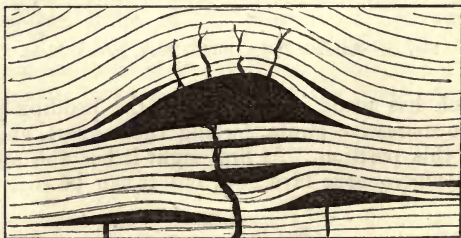


Fig. 47.—*Ideal section of a group of "Laccolites" (Gilbert).*

somewhat similar form, as in the Corndon of Shropshire and elsewhere.

104. Our largest masses of igneous rock are known as *bosses*. They are usually composed of granite, and form broad, dome-like, heath-clad mountain areas, often many miles across. Such are the granitic bosses of Dartmoor, Criffel, Cairnsmoor, Goatfell, &c. The margins of each great boss are more or less irregular; dykes, veins, and strings of granite and felsite, &c. (elvans), run out from the main granitic mass into the surrounding rocks. These are intensely burnt and altered, and near the granite itself are sometimes transformed into schists. Fragments and masses of the enveloping rock are caught up and isolated in the granitic material, and more or less metamorphosed. The great size of these bosses, the proofs of intense

alteration in the surrounding rocks, and the inclusion and apparent absorption of fragments of stratified material, have led some investigators to conclude that these granitic masses are merely the rocks of the district where they appear, melted down by the interior heat of the globe. It is far more probable, however, that they are really laccolites or intrusive sheets upon a gigantic scale, the plane of intrusion and separation, instead of being confined to a single bedding-plane, crossing the bedding of the rocks of the district more or less irregularly and obliquely. It has been also suggested that these bosses represent the subterranean cisterns whence some of our ancient volcanoes drew their supplies of igneous material. There is much to be said in favour of this view, but it is not unlikely that many of them had no real connection with the surface.

## JOINTS IN IGNEOUS ROCKS.

105. Like the sedimentary rocks, the igneous rocks are more or less cut up by cross fissures or joints. Where the igneous sheets are dense and homogeneous, and the opposite sides parallel, the jointing is remarkably regular and beauti-

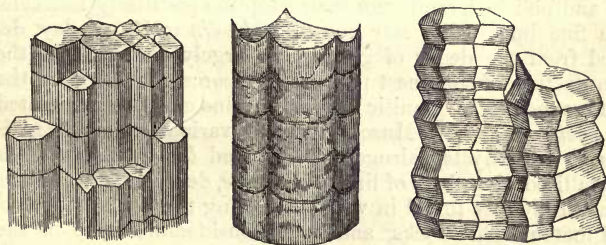


Fig. 48.—*Columnar aspects of Basalt.*

ful. Such are the joints in the basaltic lava flows of Staffa and Antrim. As the igneous mass cools it contracts, and the diminution in bulk is compensated by the formation of a set of hexagonal fissures, which pass inwards at right angles from the cooling surfaces till they meet, cutting up the lava flow into a series of more or less regular hexagonal columns. In Antrim, the natural pavement of the Giant's Causeway is formed of the bared upper surfaces of these columns. In

Staffa, a columnar lava flow of this nature, covered above by a non-columnar mass, has been breached by the waves of the sea, and we have the beautifully picturesque phenomena presented by Fingal's Cave. Similar features are presented by many dykes which break up into transverse and more or less horizontal columns. When such columns are cut by a series of transverse joints, the edges of the segments are easily attacked by atmospheric agency, and weather down into masses of globular or ellipsoidal shape, each showing an unaltered core surrounded by a series of concentric shells of weathered rock.

#### INDUSTRIAL ASPECTS OF THE IGNEOUS ROCKS.

106. The industrial purposes to which *granitic rocks* are applied are alike numerous and important. As a durable building-stone for heavy structures, like docks, bridges, lighthouses, and fortresses, the harder varieties of granite are invaluable. As an ornamental stone for monuments, halls, chimney-slabs, pillars, pedestals, and the like, some varieties of granite (Peterhead, Cairngall, &c., in Aberdeenshire; Mull in Argyleshire; Dalbeattie in Kirkcudbright; and Shap in Westmoreland) are greatly used—the beauty and sparkle of their variegated texture, and the perfection to which they can be cut and polished, rendering their adoption peculiarly desirable. The fine impalpable clay known as *kaolin* or China clay, derived from the decay of granite, is largely employed in the manufacture of the finest pottery and porcelain. Among the minor products of granitic rocks and veins may be enumerated *Muscovite mica* or “Muscovy glass,” various coloured *rock-crystals* (amethysts, cairngorms, &c.), and *beryls*. *Apatite*, or crystallised phosphate of lime (Gr. *apatè*, deceptive), is another mineral product found in veins traversing the earlier igneous and metamorphic rocks, and is of considerable value in the preparation of phosphorus and of artificial manures.

107. The scenery produced by assemblages of *trap* hills, or the hills formed of the contemporaneous and intrusive igneous rocks of the older geological formations—their crags, terraced slopes, and winding passes—is often extremely picturesque and beautiful; and the soil produced by their decomposition is generally so dry and productive, that the term “trap-district” is usually regarded as synonymous with amenity and fertility. This arises partly from their fissured and columnar structure affording an efficient natural drainage, partly from their easy disintegration into soil, partly from

the dark colour of these soils rapidly absorbing the solar heat, and partly, also, from their mineral composition, which is rich in soda, potash, lime, and other elements of fertility. The industrial purposes to which these ancient volcanic rocks are applied are numerous enough, but not of prime importance. Some basalts and greenstones, &c., make very durable building materials, but the difficulty of working such hard and refractory masses prevents their extensive use. Their hardness, however, renders them peculiarly fitted for road material; hence their extensive use in causewaying and macadamising. From the *geodes* or crystal-bearing vesicular cavities of the amygdaloids and trap-tuffs, are obtained most of the chalcedonies, agates, jaspers, and carnelians made use of by the lapidary and jeweller.

108. In an industrial point of view, recent volcanic products are also of considerable importance. All, or nearly all, the *sulphur* of commerce is derived from volcanic districts. Several of the *lavas* make a light and durable building-stone, others are cut and polished for ornamental purposes like marble, and some of the harder and more granular are used as crushing and grinding wheels. *Pumice* has been long used as a polishing or rubbing stone. *Obsidian*, as its name is thought to imply, was used by the ancients for mirrors; and the natives of various regions have used it, as our forefathers used flint, for knives, hatchets, and arrow-heads. Like the amygdaloidal trap-rocks, many of the older lavas yield *agates*, *chalcedonies*, and other precious minerals.

#### RECAPITULATION.

109. The igneous rocks were arranged by the earlier field geologists in three groups, according as they were (a) apparently associated with the oldest strata, (b) occurred in the fossiliferous rocks, or (c) were eruptive in the most recent stage of the earth's development. The first were classed as *Plutonic* or granitic, the second as *Trappean*, and the third as *Volcanic*. The field geologist of the present arranges them, not according to their geological age, but according to their stratigraphical relationships, into *Contemporaneous* or *Interstratified*, as *Subsequent* or *Intrusive*, or as *Plutonic* and *Volcanic*,—meaning by the former those igneous rocks injected and cooled at great depths, and by the latter those which have been erupted at the surface in all ages. The bedded ashes of ancient volcanoes are known as *Tuffs*, the heterogeneous masses

of fragments and breccia as *Agglomerates*, which latter occur usually in the filled-up throats, vents, or *necks* of denuded volcanoes. The *lava flows* are distinguished by their *scoriaceous exterior*, their internal *fluxion-structure*, and their *amygdaloids*. The intruded and plutonic igneous rocks make their appearance in *Necks*, *Veins*, *Dykes*, *Sheets*, *Laccolites*, and *Bosses*. *Veins* are the igneous fillings of the small irregular fissures of rocks. *Dykes* are formed of the solidified igneous material filling wider fissures with parallel and more or less vertical walls. *Sheets* are broad layers of igneous matter intruded along the plane of bedding between two successive strata. When the upper of the bounding strata is bent upwards in a great arch, while the lower retains its position, we have a *Laccolite*. Where the cavity containing the intruded igneous material is a fissure of the form of a laccolite, but whose boundaries are more or less oblique and irregular as regards the stratification, the intruded mass is said to form a *Boss*.

110. The igneous rocks, like the sedimentary strata, are cut up by joints. Where the igneous mass is irregular in form, and of vast dimensions, as in the case of granite, a few irregular master-joints alone are conspicuous. Where the igneous mass is thin, and is bounded by parallel surfaces, as in lava flows, lava sheets, and dykes, the jointing is extremely regular, and gives rise to hexagonal columns (basaltic jointing). Cross-joints in these columns form what is known as *ball-and-socket* structure, and the weathering of jointed rocks by atmospheric action gives origin to the *concentric* structure, the weathered rock resembling a pile of cheeses or cannon-balls.

## CHAPTER VII.

### THE ALTERED AND METAMORPHIC ROCKS.

#### AGENCIES AND VARIETIES OF ALTERATION AND METAMORPHISM.

111. WE have already seen that both Aqueous and Igneous rocks undergo more or less alteration subsequent to their original formation. The Aqueous rocks become hardened and consolidated by infiltrating cements,—silica, lime, or iron; while these cements again may be subsequently removed and carried off by springs and rivers. The Igneous rocks may have their hollows filled up by materials deposited from percolating waters, or their minerals may become more or less decomposed, certain soluble ingredients being carried off entirely, so that in time even the chemical composition of the rock may become greatly changed. The ultra-basic rocks degenerate into serpentine, and even granite is left as a soft mixture of grains of quartz, mica, and impalpable kaolin. Again, rocks become cut up by fissures and joints caused by contraction, by torsion of the earth crust, and the like, until, eventually, as in the case of a mass of coal, what was originally a tough carbonaceous peaty clay may break up under the hammer into a thousand cuboidal fragments. But in all these cases the originally bedded and fragmentary, or massive and crystalline structure of the rock is still discernible, and the rock is simply said to be *altered*.

112. Where, however, great masses of igneous material have forced their way up into fissures of the earth crust, they bake the rocks into which they are intruded, changing the clays into *lydian-stones*, the sands into *quartzites*, and the limestones into *marbles*—in other words, setting up within them new internal textures. Again, the irresistible crushing forces

generated in the earth crust by the lateral pressure so strikingly manifested in the elevation of continents and the wrinkling up of mountain-chains, effect the most startling changes in the structure and in the texture of all rocks locally subjected to their influence. Clays and shales are crushed into *slates*; the original bedding becomes obliterated, and the rock now opens in parallel sheets, the surfaces of which have only a subordinate relation to the original layers of sedimentation. Finally, where the pressure has been most intense, the igneous rocks themselves have not only been forced to assume a slaty structure, splitting up into irregular slaty layers of various degrees of fineness, but the minerals have apparently recrystallised in new and different forms, giving rise to what are known as schistose rocks. To the extreme cases of alteration the geologist applies the term *Metamorphism* (Gr. *meta*, beyond; *morphe*, shape); such rocks as have wholly lost their original characters, either of chemical composition, of texture, or of structure, being termed generally *Metamorphic rocks*. But it must always be carefully borne in mind that this application of the term is a mere matter of convenience, for there is every gradation in nature between the most recent unconsolidated deposits, through the hardened, altered, and cleaved rocks, up to the most highly metamorphic mass which has lost every trace of its original characters.

113. This Alteration and Metamorphism of rocks may be effected by one or more of three chief natural agents:—

(1.) *By the action of water* (Hydro-metamorphism)—i.e., by waters infiltrating from above charged with carbonic acid, &c., or by hot waters rising from below. (2.) *By the action of heat* (Pyro-metamorphism), by intruded masses of igneous rocks, bosses of granite, and the like. (3.) *By the action of lateral pressure* or crust-creep (Dynamo-metamorphism).

Most rocks, modified solely by the first of these agencies, still retain their original structure, and are said to be *altered*. Rocks affected by the action of heat (often known as *Contact-metamorphism*) usually retain their original structures; but such as have lost their original texture, and become crystalline, are classed as *metamorphic*. Of those affected by the agency of crust-creep (more generally known as *Regional-metamorphism*), the slates have lost their structures, but retain their fragmentary texture, and are classed with the altered rocks; while the schists, in which both the original structure and texture have been superseded by others totally distinct, are classed as metamorphic. In brief, the term meta-

morphic is applied to a rock which is at present crystalline, and has lost its original texture or structure. But rocks at present non-crystalline, however changed, are classed as altered rocks. The student will, however, find many exceptions to this general rule in geological works, due more or less to the theoretical views of the writer.

#### (1.) CHEMICAL, AQUEOUS (OR HYDRO-) METAMORPHISM.

114. The alterations effected in rocks by the agency of percolating waters have been alluded to more than once already. Most ordinary mineral constituents of rocks can be dissolved to a slight degree by ordinary waters. This action is, however, increased by the addition of carbonic acid to the waters, and accelerated by the aid of subterranean heat. Carbonate of lime is removed, impure limestones become *rottenstone*. Silica is carried off in the same way, and is sometimes redeposited in the interstices of loose sandstones, cementing the grains of sand into a solid mass, forming the dense glassy *quartzite*. The peridotites are slowly transformed into *serpentine*. Even the metals themselves may be dissolved and carried off, to be redeposited in faults and fissures as veins of quartz and other minerals, forming valuable lodes or *metalliferous veins*.

#### Metalliferous Veins.

115. *Metalliferous veins* or *mineral lodes* occur usually in hard rocks, slates, schists, granites, and metamorphic rocks. They are normally fault-planes or fissures, once more or less open and traversed by percolating waters, but now more or less sealed up by a deposit of mineral matter upon their walls.

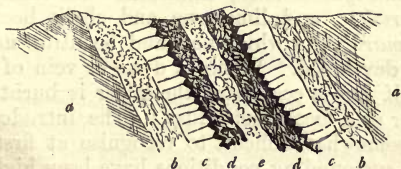


Fig. 49.—Generalised Section of Mineral Vein (Huel Mine, Cornwall). *a a*, Killas, or Slate of district; *b b*, Chalcedonic quartz; *c c*, Crystallised quartz; *d d*, Galena; *e*, Chalybite.

As these minerals have been deposited from solution, they are more concentrated, and in larger masses and crystals,

than in the surrounding rocks. The chief minerals occurring in these veins are *calcite* (calc-spar) and *silica* (quartz). Veins of the latter are often rich in metals. The minerals in the veins occur usually in layers, parallel to the bounding-walls of the fissure, and in the same order passing inwards from both sides; as if they had been successively deposited on the free surface of the fissure. The crystals in these layers have their apices directed towards the centre of the vein, and the layers are consequently known to the miners as *combs*. The non-metalliferous mineral matter making up the main mass of the vein (quartz, calcite, fluor-spar, &c.) is known as the *gangue* or *vein-stuff*; the valuable metalliferous mineral as *ore*. Each region has its own predominant group of ores: such as the copper, tin, and zinc ores of Cornwall; the lead and silver ores of Northumberland and the Leadhills; the gold and silver ores of Utah, &c. The minerals in all the metalliferous veins have clearly been deposited by percolating waters, probably more or less heated. But whether the whole of the mineral matter has been leached from the surrounding rocks, and from rocks once above but now removed by denudation, or whether, on the other hand, some has been brought up from the deeper portions of the earth crust by heated waters ascending from below, is still a controverted question.

## (2.) CONTACT METAMORPHISM (PYRO-METAMORPHISM).

116. The effects of *heat* in modifying the physical characters of stratified rock are seen around the margins of almost every dyke and intruded sheet of igneous matter. Shales and clays are baked into a dense flinty rock known as *porcellanite* and *lydian-stone*; sandstones are changed into a kind of *quartzite*; and limestone and chalk become transformed into *marbles*, in which new and beautiful minerals are occasionally developed. Where a dyke or vein of basalt has intruded itself into a coal-seam, the latter is burnt to a scoriaceous cinder or a loose sooty dust. (The intruded basalt in this case is somewhat difficult to recognise at first glance as such, for the surrounding conditions have been highly favourable to its rapid alteration by chemical agencies (hydro-metamorphism), and it has lost its original colour and texture, and become transformed into a pale friable rock known as *White Trap*.) But the metamorphic effects of heat are most con-

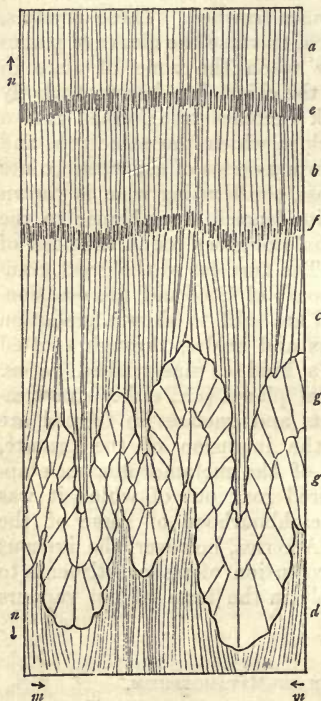
spicuous in rocks surrounding the great granite bosses. The dark-grey slates which envelop the granite mass of Skiddaw, in the Lake District, has been altered for a distance of from two or three miles from the granite. As we pass inwards from the unaltered region, pale spots begin to appear in the dark-grey slate. As we approach the granite, these spots become gradually replaced by little crystals of chiastolite, with which the slate soon becomes crowded. These crystals, along with small crystals of mica, traverse the cleavage planes at all angles. Finally, as we reach the zone of slate in contact with the granite itself, the chiastolite becomes wholly replaced by *mica*, and the rock becomes transformed into a grey *mica-schist*. Bands of rock in which the same type and sequence of alteration occurs, form a series of concentric zones around almost every granite boss, constituting what is known as its *aureole* (so called from its fancied resemblance to the golden—Lat. *aureus*, golden—halo or glory round the head of saints in classical paintings). The aureoles of the great granite bosses of Galloway in the south of Scotland, are occasionally two miles in breadth, and are said to show a gradation from the unaltered greywackes and shales, through spotted schists and mica-schists, into a kind of fine-grained *gneiss*. In all these cases the structural planes (*i.e.*, either stratification or foliation) of the schists and gneisses so formed are those they possessed before the intrusion of the granite, and the chemical composition of the metamorphic rock appears to be that of the unaltered rock out of which it was formed. In the immediate neighbourhood of some of the granite masses of Europe and America, however, the igneous rock has transferred a small proportion of its constituents to the surrounding rocks, probably in the form of hot vapours and solutions.

### (3.) REGIONAL OR DYNAMO-METAMORPHISM.

117. All the rocks altered solely by the agencies of subterranean waters and the heat of intruded igneous rock retain, as we have seen, the structural characters which they possessed previous to their alteration. Under the action of the third metamorphic agency—lateral pressure or crust-creep—the original structural characters are more or less obliterated, and an entirely new set of structural features developed; while in extreme cases the chemical ingredients of the rock rearrange

themselves, forming new mineral forms, and giving rise to a new and crystalline texture. Where a structural change alone has been brought about, the altered rock is known as a *slate*, and the new structure is called *cleavage* (the rock *cleaving* into thin parallel sheets normally distinct from those of the original stratification). Where the rock material has crys-

tallised under the process, the new structure is known as *foliation* (the rock normally splitting into *folia* or leaves of different mineralogical composition).



Cleavage.

118. In the mountain regions of Wales, Cornwall, and the Lake District, we find the shales and fine-grained rocks splitting easily into the thin parallel plates familiarly known as *roofing slates*. Where the stratification was originally marked by layers of slightly different colour, texture, or composition, we often see their layers traversing the face of the slates in parallel bands (the *stripe* of the slates), showing that the new planes of cleavage crossed the old planes of stratification at a more or less oblique angle. When a section of a coarse slate is placed under the microscope, it is evident that it is made up of particles which have been flattened out in a direction parallel with the cleavage planes; the slates splitting, in other

Fig. 50.—Vertical section of Slate Rock in cliffs of Ilfracombe (H. C. Sorby). *a b c d*, Fine-grained slates; *e f*, Fine-grained slates of darker colours; *g g*, Coarser light-coloured sandy rock with imperfect cleavage; *m m*, Direction of compression; *n n*, Direction of extension.

words, parallel with the plane of arrangement of the flattened grains. In a mixed series of shales and sandstones the cleavage

may be perfectly developed in the *fine-grained beds*, while it is totally absent from the intermediate layers of *coarser materials*. But the study of such a mixed series affords the clearest evidence of the origin of the slaty structure itself. The hard sandstones and grits are found to be crumpled up into little anticlines and synclines, showing they have been greatly com-



Fig. 51.—Slaty Cleavage. *a*, Transverse; *b*, Coincident.

pressed laterally, while they have extended themselves at right angles to this direction. The planes of cleavage in the clays are seen to be parallel with the axes of the folds in the sandstones—that is to say, lie more or less at right angles to the apparent direction of compression. In other words, the entire mass has been compressed greatly in one direction, and somewhat elongated in another, and the planes of cleavage are the new structural features generated in the process. The flattening out of the solid particles in the clayey bands has no doubt aided in the development of the cleavage structure; but Professor Tyndall has succeeded in causing even pure wax to cleave into fine laminæ by the application of great pressure.

119. Although the planes of cleavage remain, generally speaking, parallel with the average strike of the beds, the dips of the planes of stratification and cleavage themselves rarely agree. In large areas, however, where the strata are contorted, it occasionally happens that the two planes locally coincide. When this is the case, the fossils occurring on the laminæ are found to be most curiously distorted, being elongated in one direction and more or less compressed in the other. Where the cleavage planes are at right angles or oblique to the stratification, the distorted fossils are either seen cut in transverse section or have been wholly obliterated.

#### RECAPITULATION.

120. In this chapter we have glanced generally at the several agencies concerned in the alteration and metamorphism

of the sedimentary and igneous rocks ; noting their mode of action and their effects, so far as they may alter the structure or texture of the rock and yet leave sufficient evidence to give us a clue to its original character and composition ; but leaving the effects of those agencies which may entirely obliterate all the original characters, to be discussed in a further chapter. Such strata as have lost their primeval structures or primeval textures are said to be *altered*. Such as have received both new structures and new textures are strictly classed as *metamorphic* ; but the application of both these terms is variable and unsettled. The agents of metamorphism (which include the agents of alteration) are—*Water*, infiltrating through the fissures and pores of rocks, removing and replacing some of their chemical ingredients ; *Heat*, as given off in intrusive igneous masses, &c., baking, hardening, and crystallising the strata into which they are intruded ; and the *Lateral pressure* of the earth crust (crust-creep), altering the rocks subjected to its influence, both mechanically and chemically — mechanically crushing them to breccia and slates, and, in conjunction with associated chemical action, frequently transforming them from fragmentary or massive to foliated crystalline rocks.

121. By the action of *Water* (Hydro-metamorphism) are formed *rottenstones*, *quartzites*, *serpentine*, &c., and the highly important *mineral veins*. The latter are fissures in the earth crust filled with minerals, carried in by water from the surrounding rocks, or brought up from great depths. The valuable material is known as *ore*, the more or less crystalline matter in which it lies as *gangue* or *veinstone*.

122. By the action of *Heat* (Pyro-metamorphism) or of contact of intrusive igneous rocks (Contact-metamorphism), clayey rocks are changed into *porcellanite* and *lydian-stone*, sandstone into a kind of *quartzite*, and limestones into *marbles* ; and in extreme cases ordinary sediments are transformed into crystalline schistoid and gneissoid rocks. This last takes place mainly in the inner zones of the *aureoles* round granite bosses, each concentric zone of the aureole showing a lesser and lesser degree of metamorphism as it passes outwards from the granite.

123. By the action of *Crust-pressure* (Dynamo-metamorphism) finely-grained argillaceous rocks become cleaved into *Slates* ; and in certain cases all rocks may apparently become transformed into foliated schists. The new plane of division of slaty rock is known as *cleavage*, the traces of former bed-

ding as the *strike*. The strike of the cleavage of the rocks of a region agrees broadly with that of the stratification of its rocks. The dip of the cleavage has a variable relation to that of the bed, usually crossing it at a wide angle.



Fig. 52.—Block of flexured Gneiss—from a photograph.

## CHAPTER VIII.

METAMORPHIC ROCKS (*Continued*).THE FOLIATED AND SCHISTOSE ROCKS ; THEIR CHARACTER,  
ORIGIN, AND CLASSIFICATION.

124. WE now come to the most obscure and difficult branch of our subject—namely, the origin and meaning of the peculiar characters of the rocks occurring in areas of regional metamorphism. In Britain the area of the Scottish Highlands, from Perth to Cape Wrath, is mainly composed of masses of gneiss, schists, quartzites, crystalline limestones, phyllites, and slates. On the continent of Europe the regions of central and northern Scandinavia, the central parts of the Alps, the Pyrenees, &c., and other mountain-ranges, are formed of similar rocks ; and in Asia, much of the peninsula of India, and wide tracts along the chain of the Himalayas. In North America we find even larger areas, as in Canada, Labrador, and in the basin of Hudson's Bay, &c. ; while the central parts of South America, and portions of the chain of the Andes, are similarly constituted. Excluding from consideration their locally unaltered intrusive masses, the whole of the more or less crystalline rocks of these regions possesses structural features which at first glance remind us greatly of those of areas of unaltered stratified rocks, the quartzites occurring in vast beds, the gneisses splitting into sheets like flagstones, the schists cleaving into more or less regular plates like coarse shales, while the phyllites, except in their crystalline texture, are almost inseparable from ordinary clay slates. Such areas are said by the geologist to have been affected by regional metamorphism, but as to the original causes of this metamorphism the most diverse views have been held by different investigators.

## STRUCTURES OF THE SCHISTOSE ROCKS.

125. While the typically igneous rocks are recognisable by their *massive* and fluidal structures, the aqueous rocks by their *stratification*, and slates by their parallel *cleavage*, the rocks generally known as the metamorphic or schistose rocks are distinguished by their inosculating or re-entering planes of *schistosity* or *foliation*. They are divided into layers of somewhat different mineralogical composition, known as *folia* (Lat. *folium*, a leaf). These folia are not parallel sheets, but



Fig. 53.

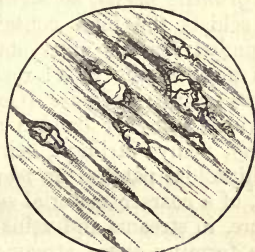


Fig. 54.



Fig. 55.

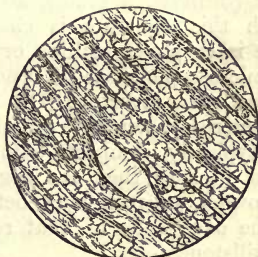


Fig. 56.

Figures illustrating the Structures of the Schistose Rocks.

Figs. 53, 54, Macro-structures. Fig. 53, *Flaser gneiss* (*Flaser structure*), *natural size*; Fig. 54, *Augen granulite* (*Augen structure*), *natural size*.

Figs. 55, 56, Micro-structures. Fig. 55, *Mylonite* (*Mylonitic structure*), *highly magnified*; Fig. 56, *Mica schist* (*Granulitic structure*) *highly magnified*.

thin lenticular plates, each plate thickening in the middle, dying insensibly away in a short distance, and alternating with similar plates along the same general line of direction. The matter of which the folia are composed is normally crystalline, and the crystalline particles of each folia are distinctly

interfelted with the crystalline particles of the neighbouring folia along their planes of separation, but the rock splits with more or less facility between the various folia. When the folia are thin and the mass divides with comparative ease along the planes of foliation, the rock is known as a schist; and thus we have *mica schist*, *hornblende schist*, *chlorite schist*, and the like. Sometimes the crystalline rock has a granitic texture, apparently differing from granite simply in the fact that it has a foliated structure. Rocks of this kind are known as *gneiss*, and the structure as *gneissic*, and we have *granitic gneiss*, *hornblendic gneiss*, &c. In some gneisses and schists the folia contain remarkable cores or “eyes” —rounded crystals or crystalline patches different from the main mass of the rock: rocks of this character are said to possess *augen structure* (Ger. *augen*, eyes). Others show a curious veiny or banded structure (*flaser structure*) (Ger. *flaserig*, veiny, stringy), being apparently formed of lenticles or ellipsoidal patches or *phacoids* (Gr. *phaco*, a lentil; *eidos*, like), of a coarser material set in a finer base, which flows, as it were, in streams and veins round the phacoids. When the paste forming these streams is holo-crystalline, the crystals form a microscopic *mosaic-like* ground mass, known as *granulitic* (*granum*, a grain), after the granulites of Saxony, of which this structure is characteristic. When the stream-paste is crypto-crystalline or amorphous, and lies in a flowing microscopic *tissue* of opaque fibres and strings, we have the *mylonitic* structure (Gr. *mylon*, a mill), named from the characteristic structure of the mylonites of Eriboll, which are typically compact, veined, or slaty-looking rocks, so called because they are composed of the material ground to powder, or rock-flour, between the great moving masses in the over-faults of that region, like corn between a pair of millstones.

#### FORMER THEORIES OF THE MODE OF ORIGIN OF THE SCHISTOSE ROCKS.

126. Whatever may be the origin of these structures, their effect is to divide the metamorphic masses into sub-parallel layers and sheets, like those due either to sedimentation or cleavage. By some of the former investigators of the rocks, notably Darwin, Scrope, and Sharp, the planes of schistosity were variously compared to the cleavage planes of slate, or the fluxion planes of igneous rocks, &c.; in other words, they were suggested as due to the differential motion of the parts of

the mass—or, generally speaking, to its deformation under pressure or stretching. But the vast majority of geologists were unable to harmonise this view with the fact that the planes of schistosity usually separate layers of different mineralogical composition. They noticed also that quartzites and crystalline limestones are locally associated with the foliated rocks in areas of regional metamorphism, and appear to be clearly interstratified with them. Further, they saw that the foliated rocks themselves are clearly folded, faulted, veined, and pierced by igneous intrusions in exactly the same manner as sedimentary rocks, and they naturally adopted the simpler view that the planes of foliation were planes of sedimentation. As this view had an additional confirmation in the circumstance that ordinary sediments are occasionally transformed into gneissoid and schistose crystalline rocks by the heat of the great granite bosses, the conclusion that the planes of foliation in the schistose rocks were planes of original sedimentation became generally accepted.

127. Founded upon this conclusion, two distinct theories of the origin of the rocks occurring in areas of regional metamorphism have been advocated in Britain. According to one theory, the foliated crystalline rocks are truly *primitive* sedimentary strata (Lat. *primus*, first), having been formed in the earlier stages of the earth's development, while its crust was new and of no great thickness, and under conditions consequently very different, as a whole, from those in which the subsequently formed fossiliferous strata were accumulated. They possess crystalline characters, because all the rocks of that primitive period must necessarily have all been more or less igneous and crystalline; while such metamorphism as they have subsequently undergone is comparatively trifling, and was completed before the commencement of the deposition of the fossil-bearing formations. According to a second theory, the schistose rocks are not necessarily primitive: they are ordinary sedimentary strata of various early geological ages—especially *Silurian*—which have been so deeply buried under later accumulations as to have been sunk within the metamorphic influence of the interior heat of the globe, and to have undergone crystallisation by the combined agencies of heat, water, and pressure; or, more generally speaking, their structures are original, while their textures are the results of a modified pyro-metamorphism on a regional scale. The adherents of the former theory were confident that it would eventually be demonstrated that the metamorphic

rocks lay everywhere below all the fossiliferous formation; the adherents of the latter theory were equally confident that in certain localities fossiliferous rocks actually rose from below some of the metamorphic series.

#### RECENT DISCOVERIES AMONG THE METAMORPHIC ROCKS.

128. In 1867 Sir W. Logan demonstrated that the great metamorphic series of Canada (Laurentian, &c.) rose up from below all the unquestioned fossiliferous formations of that region, and the American geologist, Dana, classed them as Archæan (Gr. *archaios*, of the beginning); but on this side of the Atlantic the results of discovery pointed for many years in the opposite direction. The great metamorphic area of the Scottish Highlands soon became famous in the history of the controversy between the advocates of the two antagonistic views, and such evidences as were obtainable could apparently be interpreted equally well in favour of either theory.

129. In the north-western parts of the Scottish Highlands, in the counties of Sutherland, Ross, and Inverness, the rocks were distinctly arranged in what appeared to be four successive rock-formations (see fig. 57). At the base were the *Lower gneisses* and *schists* of the Hebrides and Western Ross (Hebridean), answering generally to the primitive Laurentian or Archæan gneiss of Logan. On this rested a Palæozoic formation of conglomerates, sandstones, quartzites, and limestones, of sedimentary origin, and non-metamorphic, containing fossils in their highest beds of the age of the lower rocks of Murchison's Silurian system. This dipped off the Lower Gneiss to the eastward at a low angle, and was overlain in its turn by a second formation of metamorphic gneisses and schists—the *Upper Gneiss*—which was continuous with that of the central Highlands, and was covered in its turn by patches of Old Red Sandstone. Sir Roderick Murchison and his followers, looking at the order of these great formations as a whole, asserted that the apparent sequence was the natural one, and claimed the great metamorphic formation of the Upper Gneiss as metamorphosed Silurian sediments, on the ground that its rocks reposed on fossiliferous early Silurian beds, and were covered up unconformably by fossiliferous rocks of the age of the Old Red Sandstone, a formation which succeeds the Silurian in point of time. But Professor Nicol of Aberdeen, after studying the local phenomena in detail, asserted that the Upper Gneiss was everywhere

separated from the Silurian beds below by a tremendous dislocation extending from Eriboll to Skye, and that the former was, on the whole, merely a part of the lower or primitive gneiss pushed up from below, and forced over the edges of the originally overlying Silurian sediments. The greater simplicity of Murchison's view naturally led to its wider acceptance, and the question was not settled till 1882-84, when the region in dispute was studied by several geologists (Drs Hicks and Callaway, Professors Bonney, Lapworth, Messrs Peach and Horne, and others), with the final result that Nicol's view was demonstrated to be substantially correct, and it was shown that the eastern gneiss has been forced upward and onward over the edges of the newer rocks to the westward for a distance of several miles.

130. At first sight it would appear that these results would tend to the triumphant establishment of the Primitive or Archæan theory of the schistose rocks; but they were accompanied by other discoveries which were demonstrative of the fact, that while the *materials* of much of the so-called Upper Gneiss was Archæan, its *structures* were Palæozoic or later. The last three

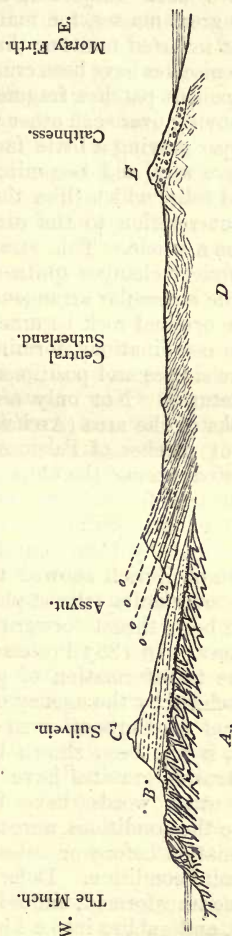


Fig. 57.—Generalised Section across the Northern Highlands.

- A, Western or Hebridean Gneiss (? Laurentian) of Archæan age.
- B, Torridon Sandstone
- C<sub>1</sub>, Eriboll Quartzite
- C<sub>2</sub>, Durness Limestone
- D, Eastern or "Upper" Gneissic Series, traversed by overfaults or thrust-planes in Assynt and Eriboll, where it includes patches of Hebridean gneiss, and altered and unaltered Lower Palæozoic strata.
- E, Old Red Sandstone strata, with fossils (Upper Palæozoic rocks).

of the investigators named above found that, under the excessive pressures to which the rocks of the north-west Highlands have been subjected, not only have the rocks been forced in great masses, for many miles to the westward, along the great inverted faults or thrust-planes, but that many of the rocks themselves have been crushed, mashed, and dragged out, their component patches, fragments, particles, and crystals *shearing* (or moving over each other with a differential motion, each higher layer moving a little farther than the one below) as the mass gave way, and becoming all finally spread out in new sheets and folia, which (like the parallel layers of slate) bear a constant relation to the direction in which the rock-mass yielded as a whole. This structural change was accompanied by chemical changes quite as extraordinary, until in certain cases the molecular arrangement of the chemical components of the original rock became broken up, and they reunited in fresh combinations, forming a new set of crystalline minerals whose shapes and positions are strictly related to the new rock-structures. Not only are masses of the original crystalline rocks of the area (Archæan and Intrusive) treated in this way, but patches of Palæozoic sediments which have become entangled among the older rocks have been sheared with them, and transformed into sub-crystalline or crystalline schists, &c. All these results agree precisely with those previously worked out by Continental investigators. In 1878 Professor Heim of Zurich showed that in the Alps enormous overfolds and overfaults (thrust-planes) occur, along which the rocks have been thrust forward for scores of miles, even in Tertiary times. In 1883 Professor Lehmann of Bonn demonstrated the transformation of granitoid rocks (intrusive) into foliated schists by the agency of crust movements acting since the date of the Carboniferous epoch.

131. Again, it has been shown by investigators in recent years that intrusive granites have become foliated in many cases, or, in other words, have become transformed into gneisses, where the conditions were apparently such as to lead to their deformation before or subsequent to their assuming a completely solid condition. Dolerite has been proved by Mr Teall to become transformed, under lateral pressure, into hornblende schists, and gabbro into a kind of augen-gneiss; while Lehmann has shown that the matrix of felspathic conglomerates, arkose, &c., may become transformed into a kind of crystalline schist or gneissic rock under earth-pressure, even while the included pebbles retain many of their original characteristics.

## DEFORMATION THEORY OF REGIONAL METAMORPHISM.

132. Founded upon the conclusions drawn from all these discoveries, a new theory of the cause of the association and of the varied petrological characters of the rocks in a district of regional metamorphism is being gradually developed at the present time—a theory most closely related to the original suggestions of Darwin, Scrope, and Sharpe. According to these new views, the rocks in such a district do not necessarily belong to any one distinctive geological period, but may be of various geological ages, owing to their present association to the effects of lateral pressure, which has more or less obscured the evidences of their original relationships. Some metamorphic areas may possibly be wholly archæan; others may be composed of patches originally either archæan, post-archæan, plutonic, sedimentary, or volcanic. The present structures of the rocks in various parts of such an area may be either original or secondary, according to the mode or degree of the local metamorphism to which they have been subjected. The granites, gabbros, &c., in such a region are unaltered plutonic rocks; the quartzites, crystalline limestones, and the like, are probably sediments only partly altered. The gneissoid rocks may be either archæan or post-archæan plutonic rocks, or felspathic sediments foliated by pressure, intrusion, veining, and the like. The schists may be either metamorphosed sediments, retaining locally their original bedding (where altered by pyro-metamorphism and the like), or dynamo-metamorphic rocks showing only secondary structures, but which may have been originally either gneissic, plutonic, or sedimentary rocks, but whose ingredients have been more or less completely rearranged both structurally and mineralogically. In fine, a metamorphic area is a *petrological complex whose altered rocks have a common foliation*. The *strike of foliation* in such a district is related to the *general strike of the sheets* of sedimentary or crystalline rocks which formed its main masses at the time of its final folding and shearing: the *dip of the foliation* is simply the *local direction of shear*—i.e., is related to the direction in which the mass to which it belonged was giving way. Like cleavage, it may locally coincide with the original bedding, but it normally crosses the bedding at an angle, and *traverses aqueous and igneous rocks alike*. The planes of schistosity are those planes along which the rocks yielded to the lateral pressure or torsion, and these *yielding planes* may be of *all grades of*

*importance*, from the great overfaults, along which solid masses of enormous extent were thrust forward, in some cases for scores of miles, down to the minutest planes separating the microscopic folia of the slaty schists. These planes cut the rock up into lenticular patches or "*phacoids*," which, like the yielding planes themselves, are of all gradations of size—from the mountain masses riding out along the great overfolds and overfaults, down to the "eyes" of the "augen" schists. The *mechanical effects* wrought by the shearing and deformation of the phacoids show of necessity a corresponding gradation, the conditions at one extreme giving rise to coarse *rock-breccias*; in medium cases to *flaser structures* and foliation; at the other extreme to the compact, stringy *mylonite*, in which the original material has been torn and ground to rock-dust. Parallel with these mechanical changes, but not necessarily accompanying them, we note a series of *chemical changes* of rising grades of importance—a larger and larger portion of the rock undergoing deformation becoming recrystallised, until finally it may all become transformed into foliated crystalline rock. The *maximum of mechanical effects* seems to have been wrought where the rock yielded to the excessive pressure and torsion mainly along certain *definite planes* (shear planes or gliding planes) or *areas* within the mass; the *maximum chemical effects* where the deforming stresses affected *all the particles* of the mass alike, the rock yielding or *flowing* in the manner of a plastic or liquid body. In some minor areas the results effected by dynamo-metamorphism possibly approximate to those wrought by pyro-metamorphism, and we may have what has been called *stratification foliation*. In general, however, the foliated rocks have been sheared, and the primary structures have all been more or less obliterated. But, as a metamorphic region may be subjected to successive earth movements acting at different times, and from different directions, we occasionally find a newer and more or less incomplete foliation crossing an older foliation, or the rocks may show traces of a foliation of a still earlier date: the successive foliation planes being in different stages of development, preservation, or obliteration.

#### CLASSIFICATION OF THE ALTERED AND METAMORPHIC ROCKS.

133. However much a rock may have been changed in structure or texture by any of the agents of metamorphism, it is tolerably clear that it was, when first formed, either an

original (*Igneous*) or derivative (*Aqueous*) rock, or has been subsequently made of a mixture of both. The most natural and philosophical classification of the altered and metamorphic rocks, therefore, would be to arrange each as a variety of the special aqueous or igneous rock out of which it has been formed. As our knowledge of the metamorphic rocks increases in the future this may be found possible; but at present, while the majority of the non-schistose altered varieties can be referred to their parent rock with tolerable certainty, we know too little of the schistose varieties to attempt this in the case of the metamorphic rocks proper. Indeed, as such rocks as mica-schist and its relatives may possibly have been derived, some from gneiss, some from granites or felsites, and some from sediments, the present impossibility of such a classification is clearly evident. In the following scheme such rocks as can with a fair approximation to certainty be referred to their natural position are classed as *Altered Rocks*, those in which the original characters appear to be wholly obliterated are classed as *Metamorphic*. It must always be borne in mind also that all the great rock-groups shade the one into the other, so that authorities rarely agree as to the separating lines between them. The aqueous rocks graduate into the igneous rocks through the tuffs and volcanic conglomerates, and the aqueous and igneous and altered rocks into the schistose rocks through the flaserites, granulites, &c.

#### A. THE ALTERED ROCKS.

##### (a) *Sedimentary.*

*Quartzite.* A hard compact rock, white, red, or brown in colour, breaking with a peculiar lustrous fracture. It is distinctly stratified, occurring usually in thick beds. Under the microscope it is seen to be composed of quartz grains, the interspaces of which are filled up by a deposit of silica. Probably an altered sandstone, the siliceous cement being a subsequent deposit carried in by percolating waters.

*Lydian-stone.* A dense black or brownish rock, extremely fine-grained, the result of alteration of a somewhat carbonaceous shale.

*Porcellanite.* A pale, close-grained, flinty rock breaking with a hackly or conchoidal fracture; due to metamorphism of fine clays or shales—so called from its resemblance to porcelain or china-ware.

*Slate.* A hard, compact, aluminous rock splitting into thin parallel layers, more or less oblique to the original stratification. When the rock still retains evidences of its primary detrital character, it is known as clay slate, green slate, roofing slate, &c. When its cleavage planes are so crowded with micaceous flakes as to present a silvery "sheen," it becomes a *phyllite* (Gr. *phyllon*, a leaf); when distinctly crystalline throughout, it becomes a

*mica slate*. The two latter varieties graduate into the typically metamorphic rock, *mica-schist*.

*Marble*. This is a granular aggregate of crystalline calcite, often mottled and veined with various impurities. When pure it has a texture like that of loaf-sugar. In metamorphosed areas it frequently contains crystals of various minerals, quartz, felspar, hornblende, garnet, &c.; flakes of steatite, serpentine, and the like. It is clearly an altered limestone. The varieties occurring in the neighbourhood of igneous intrusions occasionally contain fossils. The varieties met with in metamorphosed areas graduate into schistose limestone and calcareous schist.

#### (b) *Igneous*.

*Serpentine*. A massive, compact rock, formed of the *mineral* serpentine, of a dull-green or brownish colour, often curiously veined and mottled. It is easily cut with a knife, and frequently shows scattered crystals of enstatite, chromite, &c. It is a silicate of magnesia, and appears to be due in most cases to the alteration of a highly basic rock (*peridotite*), such as *picrite*, &c.

### B. THE METAMORPHIC, SCHISTOSE, OR FOLIATED ROCKS.

*Gneiss* (Ger. a miner's term). This name is applied to a crystalline aggregate of quartz, felspar, and mica, &c., differing from granite simply in the fact that its component minerals are arranged in folia, so that it may with difficulty be split up into sub-parallel slabs. The more finely schistose varieties shade down into feldspathic schists; the more granular varieties pass insensibly into granite. The chief varieties are named, like granite, according to their mineralogical composition—such as granitic gneiss, biotite gneiss, augite gneiss, hornblendic gneiss, &c.

*Schists* (Gr. *schisma*, a splitting or division). The name given to all finely crystalline or sub-crystalline metamorphic rocks which split up easily into folia or irregular leaves. Each variety of schist is named after its most prominent or characteristic mineral, such as *mica-schist*, *chlorite schist*, *hornblende schist*, &c.

When the schist becomes more or less massive, and the foliation is feebly developed, it is termed *Rock*, as hornblende rock, garnet rock, &c. The hornblende *rocks* and hornblende schists are sometimes united under the term *amphibolites*.

*Mylonite* (Gr. *mylon*, a mill). Normally a compact platy rock or microscopic shear-breccia formed in the numberless overfaults (thrust-planes) of mountain regions. It is composed of the flakes and particles of the rocks which have been sheared, dragged, and ground between the jaws of the fault-planes. They are set in a sub-crystalline paste, streaked with inosculating veins and fibres of more or less opaque matter. The mylonitic structure is very characteristic of those rocks which have been more or less crushed and sheared in the region of thrust-planes, and thus we have *mylonitic gneisses*, *pegmatites*, *quartzites*, and *limestones*; as well as *gneiss-mylonite*, *quartzite-mylonite*, &c.

*Granulite* (Lat. *granum*, a grain). This differs from mylonite essentially

ally in the fact that the matrix is holo-crystalline, being composed of microscopic granules of quartz and felspar, forming a kind of mosaic. The chief varieties are *garnet-granulite*, *gabbro-granulite*, *augen-granulite*, &c.

*Flaser gabbro*, *flaser gneiss*, &c. Igneous or gneissic rocks which have been crushed by the earth pressure into lenticular masses separated from each other by folia or wavy films of finer crystalline material.

*Augen gabbro*, *augen gneiss*, *augen schist*, &c. Igneous or metamorphic rocks showing "eyes" or inclusions of crystals, &c., set in a finer crystalline and foliated ground mass.

#### SCENIC AND INDUSTRIAL ASPECTS OF THE ALTERED AND METAMORPHIC ROCKS.

134. The physical aspect of metamorphic districts is bold, rugged, and barren. Thrown into lofty mountains, consisting of rocks of unequal hardness, and long subjected to meteoric waste and weathering, it is chiefly among gneiss and mica-schists that those deep glens and abrupt precipices occur, which give to highland scenery its well-known wild and picturesque effect. As already stated, the igneous rocks which disturb the gneiss and mica-schists are chiefly granitic, breaking through and inter-ramifying with them in very complicated relations. Basic igneous rocks—as dolerite and greenstone—are also found traversing these groups in the form of dykes and protruding masses; and occasionally still more recent effusions of basalt are found passing through not only the gneiss and mica-schists, but through their associated dykes and veins of granite and porphyry.

135. The industrial or economic products derived from the gneisses and schists are by no means numerous. Several of the metallic ores—such as tin and copper, and very rarely gold—occur in veins traversing these rocks. The limestones, from their highly saccharoid texture, and mottled and veined appearance, yield valuable marbles; and serpentine, when found in solid masses, produces also a very elegant material for internal decoration. Quartzite, when sufficiently pure, is quarried in several places for the potteries—the large blocks being used for grinding the calcined flints now so largely employed in the manufacture of the finer ware. Potstone, or the *lapis ollaris* of the ancients, of which jars and vases are sometimes manufactured, steatite or soapstone, and amianthus or flexible asbestos, which may be woven into fabrics indestructible by fire, and is now used for steam-packing, are also products of these rocks. One of the most valuable substances derived from them is *graphite* or *plumbago*, so largely em-

ployed for writing-pencils, for polishing, for crucibles, and similar purposes. Garnets, rock-crystals, tourmalines, beryls, and other precious minerals, occur either in the rocks themselves or in the veins that traverse them.

136. The industrial applications of *clay-slate* are numerous and well known. The hard fissile varieties have long yielded a most valuable roofing material; the finer sorts are used for writing-slates and slate-pencils; and the thicker-bedded kinds are now largely employed as an ornamental stone for vases, tables, chimney-slabs, mosaic pavement, cisterns, and other architectural purposes. The clay-slate in many districts is traversed by metalliferous veins, and from these are obtained ores of tin, copper, lead, silver, and not unfrequently gold.

#### RECAPITULATION.

137. Of all the rocks altered by metamorphic agency, the schistose rocks occurring in areas of regional metamorphism are the most difficult of study and classification. Those met with in the typical British region of the Scottish Highlands include (1) *quartzites*, *marbles*, and *slates*; (2) *gneisses*, *schists*, and *phyllites*; (3) various types of *altered* and *unaltered plutonic* rocks. The aqueous origin of the first of these groups, and the igneous origin of the last, are both equally evident; but of the *foliated gneisses* and *schists* it is impossible to assert, without the most minute examination, whether they were originally aqueous or igneous, or indeed whether they retain in many cases any trace whatever of their *original* structures and textures. Formerly, the bedded character of the foliated rocks in general was taken for granted by most geologists, and two theories, founded essentially upon this view, were advocated—viz., the *Primary* or *Archæan* theory, which taught that they were the first stratified products of the cooling earth crust, and the *Silurian* or *Hydro-thermal* theory, which taught that they were ordinary sediments of the earlier fossiliferous formations, chiefly Silurian, crystallised by heat, water, and pressure.

138. By the *discoveries* made in recent years in the Alps, Saxony, and the Scottish Highlands, &c., it has been made clearly evident that in mountain areas not only are the stratified rocks, and their included igneous intrusions, bent into enormous ridges and folds, but that the rocks yield to the continued pressure in inverted faults (over-faults or thrust-planes) of all dimensions, and in extreme cases may be forced

over the edges of the originally overlying rocks for great distances. The deeper-seated rocks in these folds and yielding masses are crushed and torn into lenticles (*phacoids*), and spread out in *pressure-breccias* and *slaty schists*. In other cases, the relationships of the chemical components of the rock-minerals are broken up, and they *recrystallise* in shapes suited to the new condition; becoming all finally arranged in sub-parallel layers (*folia*), lying in the direction in which the rock gave way (*sheared*). In this way, gneisses, granites, dolerites, and sediments become transformed into various kinds of crystalline and sub-crystalline schists. On these grounds, a new or *Deformation theory* of regional metamorphism is at present in course of development, according to which the schistose and gneissic structures must be mainly regarded as secondary, and therefore rocks in an area of regional metamorphism cannot be regarded like those of a fossiliferous system, for they may include rocks of different modes of origin, of different geological ages, and of different degrees of metamorphism.

139. Such *structures* and *textures* of the igneous rocks as result from the effects of dynamo-metamorphism are usually the results of the lateral movements of the rocks themselves, or of the work performed by the forces generated by crust-creep. The *mechanical* effects wrought by lateral pressure are the breaking up of the rocks affected into lenticular masses (*phacoids*) of all dimensions, which become separated by over-faults, gliding planes, or by inosculating planes and areas of less cohesion, and of shearing; and thus we have *flaser structure*, *augen structure*, *mylonitic structure*, &c., due to this cause. Pressure and shear-breccias are formed of all degrees of coarseness down to the compact, stringy *mylonite* formed of microscopic rock-dust, occurring along the great thrust-planes. The *chemical effects* wrought by dynamo-metamorphism are of correspondingly great importance. In the *mylonites* the fragmentary dust is set in a paste of sub-crystalline material. In the *granulites* the *phacoids* are set in a microscopic mosaic of quartz and felspar. In the *augen schists* all the original material has been recrystallised, with the exception of cores formed of fragmentary crystals, or patches of the original rock; and finally, in the *holo-crystalline schists* proper, the whole of the primary structures seem to have disappeared, and have been replaced by a common foliation, while all the original minerals have disappeared as such, and their molecular components have been recombined as new crystals, arranged in the new planes of schistosity.

140. Like the sedimentary and igneous series, the altered and metamorphic rocks may be roughly classified according to their composition, texture, and amount of alteration. Of the ALTERED *sedimentary* rocks, the siliceous members are, *quartzite*, *lydian-stone*, *porcellanite*; the calcareous members are the several varieties of *marble*; and the aluminous variety is *slate*. Of the altered *igneous* rocks, the most important is *serpentine*. Coming next to the SCHISTOSE rocks, we find them classified according to their structures and textures: the coarsely *granular* and *granite-like* varieties are known as *gneisses*; the thinner-leaved varieties, in which felspar is rare or inconspicuous, are known as *schists*; when homogeneous, and showing little apparent schistosity, they are known as *rock*; when compact and slaty, they are called *phyllites*. In addition to the schists proper, we have a group of rocks containing variable portions of fragmentary or crystalline material, set in a crystalline or sub-crystalline flowing paste. When the flowing paste is holocrystalline and granular, we have the *granulites*; when the matrix is sub-crystalline and fibrous, we have the *mylonites*.

## PART III.—HISTORICAL GEOLOGY.

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### CHAPTER IX.

#### CLASSIFICATION OF THE STRATIFIED ROCKS INTO FORMATIONS AND SYSTEMS.

141. WE now reach the third division of our subject—namely, that of HISTORICAL GEOLOGY—the aim of which is to classify and describe the rocks of the earth crust in the order of their formation, and to note the gradual development of life from the dawn of existence up to the present time. Of the three great provisional classes of rocks—the sedimentary, the igneous, and the metamorphic—the sedimentary rocks alone afford the necessary elements for a complete chronological scheme. Not only are they the sole repositories of the fossilised remains of former creatures, by whose study alone is it possible to trace the onward march of life upon the surface of the globe in the past geological ages; but, having been deposited quietly and slowly, layer above layer, the order of their arrangement can be definitely ascertained, and a complete chronological scale of formations can be constructed, each formation and layer being referable to its proper place in the collective series. The igneous and metamorphic rocks are practically useless for this purpose. The former break through, invade, or irregularly overlie the stratified rocks, and must, from the historical point of view, be looked upon essentially as local accidents, interruptive of the natural continuity of the aqueous sediments. The metamorphic rocks are merely aqueous or igneous formations whose original characters have been more or less obliterated.

142. In Britain, as indeed in almost all widely extended areas of the earth's surface, the stratified rocks make up the

main mass of the visible earth crust, occurring almost everywhere below the natural soil of the country, and admitting of the most detailed study in cliffs, in railway cuttings, in quarries, and in numberless natural rock-exposures. When they are carefully examined, they are found to arrange themselves in broad sheets or masses of strata, each sheet being marked throughout its extent by the same general lithological features. Thus the whole of the broad valley of the Thames, from Reading to the German Ocean, is underlain by a sheet of stratified *clays*, sands, and gravels. A band of *chalk*, five to twenty miles in width, ranges from Dorset through Wilts, Berks, Cambridge, Norfolk, and Lincoln, to the sea at Flamborough. All the central parts of England are underlain by a wide band of *red sandstone*, which is continuous from Exeter to Hartlepool; a broad band of *coal-bearing rocks* sweeps across Scotland from the Forth to the Clyde, and an equally wide zone of *greywackès* and shales from St Abbs to the Mull of Galloway. When these mighty bands of rock are studied in the sea-cliffs and elsewhere, it is found that they are in reality made up of strata several hundreds or thousands of feet in collective thickness. The London clay of the Thames valley is at least 500 feet in thickness; the chalk of the eastern counties has a depth of 1000 feet; the coal-bearing rocks of central Scotland at least 2000 feet; while the great sheets of red sandstone of central England, and of the Highland borders, attain still vaster thickness—the vertical extent of the former at its greatest is about 5000 feet, and the latter has been estimated at 20,000 feet, or nearly four miles.

143. Each of these great rock-masses is termed by the geologist a *formation*, as having been formed under special conditions more or less peculiar to itself; and thus we have the *London Clay* formation, the *Chalk* formation, the *Coal* formation, the *Red Sandstone* formation, and the like. Again, when the fossils of these formations are carefully studied, it is found that each formation is everywhere marked by the presence of special fossils, which are peculiar to itself and do not occur in the other formations, and that wherever the rocks of this formation are examined, its strata always yield these special forms. Thus the *Old Red Sandstone* formation is marked by the presence of certain remarkable *fishes*, the *Coal* formation by its abundant *flowerless plants*, the *Mountain Limestone* by its hosts of special *corals*, the *London Clays* by their remarkable tropical *sea-shells*, and the like.

144. Further, geologists have ascertained, by laying down these rock-sheets upon their maps, and by following the exposures of their strata in cuttings and in sea-cliffs, &c., that each of these formations rests upon a relatively lower or older formation, and is covered up in turn by a higher or newer one. In the sea-cliff of Dorset, for instance, the Chalk may be seen resting on the Oolite formation ; and in those of the Isle of Wight, the London clay lying above the Chalk. In the cliffs of the east coast of Scotland, the red sandstone formation may be seen clearly reposing on the greywackè formation of the southern uplands, and the representative of the Mountain limestone on the red sandstone. Not only so, but the various formations have been proved always to follow each other in the same relative order,—the London clay above the Chalk ; the Chalk above the Greensand ; the Old Red sandstone above the greywackè formation, and so on. Here and there certain formations may be *locally missing*—the Greensand may be found resting upon the red sandstone, or the Coal-measures upon the greywackès ; but in no case do they repose on formations elsewhere found higher up in the general series, or, in other words, on formations which should follow them in natural order.

145. In those cases where the series of formations is complete, there is an insensible lithological passage or shading of the rocks of the underlying formation into those of the overlying group—the colours or lithological characters of the deeper rocks gradually disappearing and becoming replaced by those of the higher formation, showing that there was a gradual change from the physical conditions which gave rise to the peculiar features of the underlying strata into those which brought about the peculiarities of the overlying rocks. There was no local upheaval of the sea-floor, but either a *depression* or a change in the character of the material swept out to sea. Where there is, on the other hand, a break in the series of formations, and one or more is missing, we usually find the newer formations resting *unconformably* upon the edges of the rocks below, and containing abundant pebbles and fragments derived from their destruction ; clearly showing that during the period of the deposition of the missing formations elsewhere, the sea-floor in the district where they are wanting was *upheaved* into dry land and *denuded*, and that no new formation was there laid down till the ground had again been depressed below the sea-level.

146. Thus there are *four main guides* to the development

of the true chronological classification of the geological formations, afforded—(a) by their distinctive lithological characters; (b) by their distinctive fossils; (c) by their containing fragments of rocks derived from other formations the actual place of which is known; and (d) by their visible superposition. Of these the first and last are naturally the most easily available; and, broadly speaking, are in themselves sufficient to enable us to lay down a complete chronological scheme of the main geological formations. It is clear that where the formations lie, as in Britain, almost horizontal in position, or but slightly inclined, the *highest* formation in the series must have been the *last* deposited, and the *deepest* formation in the collective series must be the *oldest* of all. When they are classified in this way, we find a striking corroboration of the correctness of our conclusion in the fact that the highest formations contain fossils resembling the plants and animals of the present day; while, as we descend the series, the resemblance of these to creatures of the present grows less and less, and their number and variety decrease in almost corresponding proportion; until finally, in the deepest and therefore the oldest rocks, all fossils whatever seem to disappear.

147. Founding upon these facts, geologists arrange the geological formations into five main groups, which are named as follows:—

FORMATIONS.

1. RECENT.—All superficial formations—such as sand-dunes, silt, coral-reefs, river alluvium, and the like. *These contain, broadly speaking, the remains of existing plants and animals, either unaltered or only partially fossilised.*
2. TERTIARY.—Deposits of regular strata occurring below the Recent deposits and above the *Chalk*, containing the remains of plants and animals not differing widely in character from those now existing.
3. SECONDARY.—Embracing all the strata known as *Chalk*, *Oolite*, *Lias*, and *New Red Sandstone*. *Contain fossil plants and animals of species altogether different from those of the present, but allied to them in their general characters.*
4. PRIMARY.—Including the *Coal Measures*, *Old Red Sandstone*, &c., down to the base of the *Cambrian* system. *Contain fossil animals totally distinct from those of the present, both specifically and in general type.*
5. ARCHÆAN (Gr. *archaios*, ancient, belonging to the beginning).—Including the rocks below the *Cambrian* formation, usually highly metamorphic, and destitute of all except the most doubtful traces of organised existences.

148. When we come to study the various formations in

greater detail, we discover that certain special formations generally occur in association, and always contain a closely related set of fossils. The geologist unites these allied formations into what he terms a *System*—such, for example, as the *Carboniferous System*, including the formations of the Mountain Limestone, the Millstone Grit, and the Coal Measures; or the *Cretaceous System*, embracing the Chalk, the Greensand, and the Wealden. Each system, again, may be broken up into *Divisions*—*Lower, Middle, and Upper, &c.*—each embracing one or more formations. The formations or divisions themselves may be separated into *Series*, each including a number of *Groups* of strata or beds having certain lithological or zoological characters in common; and these groups may be finally broken up into *Zones*, or minor groups of strata, each zone being characterised by the presence of some special or peculiar fossil. The geological systems and their chief divisions and formations, as recognised in Britain, are given in the following table. Their names are of various origin. Some have been founded upon the special lithological characters of the system—as the Chalk and Greensand; others from the region where the rocks of the system are most typically developed—as the Permian, Cambrian, &c.; others on chronological considerations—as the Tertiary, Old Red Sandstone, &c.

#### A. RECENT.

##### I. POST-TERTIARY OR QUATERNARY SYSTEM, including

- (a) *Recent and Prehistoric* formations, comprising alluvium of present rivers and lakes, sand-dunes, peat-mosses, &c. *Remains of plants and animals belonging to species now existing, or but recently, and it may be locally, extinct.*
- (b) *Pleistocene or Glacial* formations, including the deposits of the “Great Ice Age,” cave deposits, and older river gravels, &c.

#### B. TERTIARY.

##### II. TERTIARY SYSTEM, embracing all the regularly stratified clays, sands, marls, limestones, &c., lying above the Chalk and below the Drift, arranged into *Pliocene, Miocene, Oligocene, and Eocene* divisions. *Remains of plants and animals for the most part extinct, especially in lower beds, but not differing widely from existing species.*

#### C. SECONDARY.

##### III. CRETACEOUS SYSTEM (Lat. *creta*, chalk), embracing the *Chalk, Greensand, and Wealden* formations. *Remains of animals and plants belonging to species now extinct.*

##### IV. JURASSIC SYSTEM (after the Jura Mountains), comprising the two divisions or sub-systems of the *Oolite* and *Lias*, each composed of

several subordinate formations. *Remains of plants and animals (the most remarkable being huge reptilia) belonging to genera now extinct.*

- V. TRIASSIC SYSTEM (Lat. *tres*, three—so called from its triple division in Germany), composed in Britain of the two divisions of the *Keuper* and *Bunter*. *Few organic remains; such as are present being more closely allied to those of Jurassic rather than to Carboniferous.*

#### D. PRIMARY.

- VI. PERMIAN SYSTEM (so called from Perm in Russia, where its strata are well developed), including the formations of the *Permian Sandstones* and *Magnesian Limestones*. *Remains of plants and animals generally of the same types as those of Carboniferous strata.*
- VII. CARBONIFEROUS SYSTEM (Lat. *carbo*, coal), containing the *Coal Measures*, *Mountain Limestone*, and *Millstone Grit*. *Remains of plants and animals abundant; totally distinct in type from those prevalent at the present day.*
- VIII. DEVONIAN (after Devon) or OLD RED SANDSTONE SYSTEM (so called to distinguish it from the New Red Sandstone, a name formerly applied to the combined Permian and Triassic Rocks). *Often barren, but remains of fishes abundant in some localities, marine shells abundant in others.*
- IX. SILURIAN (from the *Silures*, inhabitants of South Wales). Shales, greywackes, and limestones. *First vertebrata, fishes. Often crowded with corals, and shells of peculiar types (Brachiopods).*
- X. ORDOVICIAN (from the *Ordovices*, the ancient inhabitants of North Wales). Shales, greywackes, and slates. *No vertebrata, remains of Zoophytes in greatest abundance (Graptolites).*
- XI. CAMBRIAN (from Cambria, the ancient name of Western Wales). Slates, grits, and conglomerates. *First undoubted fossils, chiefly Crustacea (Trilobites).*

#### E. ARCHÆAN.

The Archæan rocks of Britain, barren of fossils, and occurring only in isolated patches, have been broken up into local groups, which cannot, however, be yet looked upon as true geological systems. Such are the *Lewisian* or *Hebridean* rocks of North Scotland, the *Pebidian* of St David's, and the *Uriconian* of the Wrekin and Charnwood. In North America the Archæan rocks have been divided into *Laurentian* (from the Laurentide Mountains of Canada) or Lower Archæan, and the *Huronian* (from L. Huron) or Upper Archæan. Other names have been proposed for various members of the series, but as yet have not met with such general acceptance.

149. It will be apparent from the foregoing descriptions, that when the fossils of the various geological systems are studied, we find in the recent formations *species* identical with

those living in our modern seas, while in the tertiary formations these disappear one by one, and their place is taken by others, until, by the time we reach the base of the tertiary strata, the recent species have wholly disappeared. In the secondary rocks, while it is true that none of the species are identical with those of the present, nevertheless they are closely allied to them, while the *genera* or larger groups are of the same type as those of to-day. In the primary rocks, however, even the modern genera have largely disappeared, and the life types are totally distinct from those of the present. In other words, the primary rocks contain collective fauna of an *ancient* type; the tertiary and recent rocks a fauna of a *modern* type; and the secondary rocks a fauna of a type more or less of a character *intermediate* between these two extremes. This circumstance has led to the division of the collective fossils of the geological systems into three successive faunas: (1) the *Palæozoic* fauna (Gr. *palaïos*, ancient; *zoe*, life) of the primary rocks; (2) the *Mesozoic* fauna (Gr. *mesos*, middle) of the secondary rocks; and (3) the *Cainozoic* (Gr. *cainos*, recent) fauna of the tertiary and recent formations. The dubious fauna of the *Archæan* rocks has been named by some the *Eozoic* (Gr. *eos*, dawn); while by others the *Archæan* rocks are denominated *Azoic* (Gr. *a*, without; *zoe*, life), or *Hypozoic* (Gr. *hypo*, under). In other words, we have, in the history of the development of life upon the globe, a series of stages analogous to those of the periods of the history of mankind—the *Eozoic* period answering broadly to the prehistoric or mythical period of human history; the *Palæozoic* to that of ancient history; the *Mesozoic* to that of the middle ages; and the *Cainozoic* to that of modern history.

150. Such are the terms in general use among geologists, but they are admittedly defective in several respects. The *Palæozoic*, whether regarded as including the grander masses of sediment, or from the point of view of the distinctness of its fossils, is certainly of far greater importance than either the *Mesozoic* or *Cainozoic*. Hence, by some geologists, the two latter are grouped together as *Neozoic* (Gr. *neos*, new). By others the *Palæozoic* itself is divided in the same way as the *Neozoic* into two periods—(a) the *Proterozoic* (Gr. *proteros*, former), including the Cambrian, Ordovician, and Silurian; (b) the *Deuterozoic* (Gr. *deuteros*, second), embracing the Devonian, Carboniferous, and Permian; while the Quaternary is separated as the *Psychozoic* (Gr. *psyche*, the mind or soul), or *Anthropozoic* (Gr. *anthropos*, man). This last, or most

detailed arrangement is that which answers most closely not only to the *palæontological*, but also to the *physical* facts in British geology. The *Archæan* rocks of Britain are largely crystalline (metamorphic) or volcanic, and are non-fossiliferous. The *Proterozoic* rocks are of marine origin, and have a fauna composed exclusively of invertebrata. The *Deuterozoic* formations were laid down mainly in lakes, estuaries, or in shallow waters, and are marked by fossils of mail-clad fishes and flowerless plants. The *Mesozoic* rocks above the Triassic are largely marine, and are characterised by abundant reptiles and cuttlefish. The *Cainozoic* formations are shallow-water deposits, largely estuarine, and contain abundant sea-shells of genera now largely prevalent in tropical regions. The *Anthropozoic* formations are all terrestrial in origin, and afford more or less reliable traces of the existence of man.

151. Combining all these facts and conclusions in one general scheme, we have the arrangement given upon the following table:—

GENERAL TABLE OF THE STRATIFIED SYSTEMS  
AND FORMATIONS.

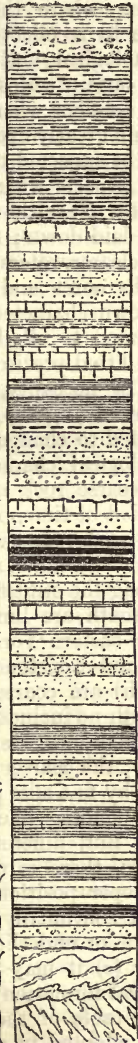
QUATER- NARY.	TERTIARY.	NEOZOIC.	ANTHRO- POZOIC.	POST- TERTIARY.		Recent and Prehistoric.
						Pleistocene or Glacial.
			CAINOZOIC.	TERTIARY.		Pliocene.
						Miocene.
SECONDARY.			MESOZOIC.			Oligocene.
						Eocene.
				CRETACEOUS.		Chalk and Gault.
						Neocomian and Wealden.
PRIMARY.			DEUTEROZOIC.			Upper Oolite or Portlandian.
				JURASSIC.		Middle Oolite or Oxfordian.
						Lower Oolite or Bathonian.
						Liassic, Upper, Middle, and Lower.
ARCHÆAN.			PROTEROZOIC.			Rhætic.
				TRIASSIC.		Keuper.
						Bunter.
				PERMIAN.		Magnesian Limestone.
			PALÆOZOIC.			Permian Sandstone.
						Coal Measures.
				CARBONIFEROUS.		Millstone Grit &c.
						Carboniferous Limestone.
			EZOIC.			Upper Devonian.
				DEVONIAN and OLD RED SANDSTONE.		Middle Devonian.
						Lower Devonian.
						Ludlow.
				SILURIAN.		Wenlock.
						Llandovery.
						Caradoc or Bala.
				ORDOVICIAN.		Llandeilo.
						Arenig.
						Lingula Flags.
				CAMBRIAN.		Menevian.
						Harlech.
						Uriconian and Pebidian.
				HURONIAN and LAURENTIAN (of America).		Hebridean, or Lewisian, &c.

Fig. 58.

152. Such is the *Geological Record*, as drawn up from evidences afforded mainly by the geological formations of those British localities, where they occur in their typical aspect. But we have to recollect that a marine geological formation, whose lithological and zoological characters are constant, is merely a certain series of rocks which were laid down on a part of the sea-floor where the conditions remained practically the same for a greatly extended period of time ; and thus no formation can be expected to retain precisely the same physical or zoological aspects when followed over enormous areas of the earth crust. Near the sea-shore coarse materials, gravels, and sands are laid down ; farther out to sea we have muds and silts ; in the clearer waters limestones and coral-reefs ; in the profound depths oozes and impalpable clays. Each of these areas has its own characteristic set of organisms : a few forms may be common to all, but the bulk of the *fauna* is locally peculiar, and fitted precisely to the local conditions. It follows, therefore, of necessity, that each of the British formations, when followed to great distances from the typical locality, may be expected to change insensibly both in lithological and palæontological characters. Not only so, but thousands of feet of coarse rock may be laid down offshore, while, in the same period of time, only a few feet of fine silt may be carried into the deeper parts of the ocean. Phenomena which find their natural explanation in these facts, occur everywhere among the stratified formations. Thus the Liassic rocks of the south are limestones, marls, and clays ; as we cross England to eastern Yorkshire they gradually pass into estuarine shales and ironstones. The Silurian rocks of North Wales (Denbigh) are coarse grits and sandstones of enormous thickness, with no included limestones or calcareous beds ; but when followed into western and central England they thin away rapidly, the coarser materials gradually disappear, and are replaced by fine silts and shell-beds. These are merely types of corresponding phenomena in the geological formations generally. But, different as the local characters of a formation may be, there is usually no great difficulty in placing it in its proper position in the general scale—for (a) it may be followed continually across its outcrop ; (b) it may be proved to overlie or underlie certain known and recognisable formations ; or (c) it may contain certain characteristic fossils of the typical formation to which it belongs.

153. The geological table of the British formations given above is that which is adopted in principle by geologists, not

only in Britain, but both in Europe and America. Some of the British formations, as, for example, the upper Jurassic and Cretaceous formations, can be recognised on both sides of the Straits of Dover, and their geographical distribution in France is such as to show beyond question that they were once continuous beneath the English Channel. Formation for formation, zone by zone, they can be traced from the Atlantic far into the Alps and the Jura, containing the same characteristic fossils, and occupying always the same relative position with respect to each other. Resting *above them* we find the tertiaries, in the same order as in Britain, but vastly augmented in thickness and in variety of fossils. From *underneath* them emerge the palæozoic rocks in their natural order, one below the other—here thinner, there thicker—here present in complete sequence and with their characteristic fossils, there showing various members to be absent in local unconformities and the like; until finally, *below all*, we reach the fundamental rocks of the Archæan, wrinkled, metamorphosed, and barren of all traces of organised existence. In America all these systems can be recognised as in Europe, showing the same general sequence of life. The fossils in the corresponding systems on the other side of the Atlantic may differ in minor detail; but the life-type,—proterozoic, deuterzoic, &c., shows the same or a corresponding gradation. The same rule obtains wherever the strata of the earth crust have been studied. In each great region the local conditions of sedimentation were different, and the life forms vary specifically from region to region, but everywhere there is evidence of repeated denudation, deposition, and continuous change of life-type, as far as the eye of the geologist can discern. Everywhere the grand upward and onward march of life has been practically the same, from the dawn of animated existence up to the advent of man.

## RECAPITULATION.

154. The purpose of the preceding chapter has been to exhibit the classification adopted by geologists in describing the various rock-formations which constitute the crust of the globe. The basis upon which such a chronological arrangement is founded are (1) *order of superposition*, (2) mineral composition, and (3) fossil contents. By these aids the order of sequence in time among the stratified rocks has been pretty accurately ascertained, and they have been classified into *systems*, and the systems again into *divisions*, formations or

*series, groups and zones*, in gradually descending order of importance. In making such an arrangement, it is not affirmed that any portions of the earth crust exhibit these rock-systems one above another like the coats of an onion, but simply that though several formations may be wanting in certain districts, such formations as are present are never found out of their order of succession. Beginning at the surface, we have thus in descending order—

1. Quaternary, post-tertiary, or recent accumulations.
2. Tertiary strata.
3. Cretaceous or Chalk.
4. Jurassic, or Oolitic and Liassic series.
5. Triassic, or Upper New Red Sandstone.
6. Permian, or Lower New Red Sandstone.
7. Carboniferous.
8. Devonian, or Old Red Sandstone.
9. Silurian.
10. Ordovician.
11. Cambrian.
12. Pre-Cambrian, or Archæan Rocks, including the so-called Laurentian and Huronian of America, and the Hebridean and Pebidean Rocks of Britain.

As regards the relative age and systematic position of these systems, they are grouped into *Archæan, Primary, Secondary, Tertiary*, and *Quaternary*. All the formations above the Archæan are frequently spoken of as the *Fossiliferous rocks*, because they contain in more or less abundance unequivocal remains of animals and plants; while the *Archæan* rocks, which have afforded only dubious traces of life, have been termed *Non-fossiliferous*. Referring more especially to the fossil contents of the formations, the term *Neozoic* (new life) is applied to the life characteristic of rocks of the Quaternary, Tertiary, and Secondary periods; the term *Palæozoic* (ancient life) for that of the Primary period; while the term *Azoic* (destitute of life) or *Eozoic* (dawn of life) is employed for Archæan time. Each of these great life periods is again subdivided for the purpose of more exact classification; the Neozoic into *Anthropozoic* (life of man); *Cainozoic* (recent life), *Mesozoic* (middle life), and the Palæozoic into *Deuterozoic* (second life), and *Proterozoic* (earlier life). By employing the classification thus indicated, every geologist, in treating of the rocks of a district, uses a terminology intelligible to other geologists, and all the more intelligible from the circumstance

that it is a classification founded on natural facts, and not on mere arbitrary or technical distinctions.

155. The subjoined tabulation presents the whole series of systems, groups, and periods as recognisable in the rocks of Britain :—

TABULAR ARRANGEMENT OF ROCK SYSTEMS.

PRIMARY DIVISIONS.	SYSTEMS.	FORMATIONS.	LIFE-TYPES.
QUATERNARY.	POST-TERTIARY.	{ Recent. Glacial or Pleistocene.	{ ANTHROPOZOIC.
TERTIARY.	TERTIARY.	{ Pliocene. Miocene. Oligocene. Eocene.	{ CAINOZOIC.
SECONDARY.	CRETACEOUS.	{ Chalk or Upper Cretaceous. Neocomian or Lower Cretaceous.	{ MESOZOIC.
	JURASSIC.	{ Oolitic (Upper, Middle, Lower). Liassic.	
	TRIASSIC.	{ Rhætic. Keuper. Muschelkalk (of Germany). Bunter.	
PRIMARY.	PERMIAN or DYASSIC.	{ Magnesian Limestone. Permian Sandstone. Coal Measures.	{ DEUTEROZOIC.
	CARBONIFEROUS.	{ Millstone Grit. Mountain Limestone Series.	
	OLD RED SANDSTONE or DEVONIAN.	{ Upper, Middle, and Lower Divisions.	{ PROTEROZOIC.
	SILURIAN.	{ Ludlow. Wenlock. Llandovery.	
	ORDOVICIAN.	{ Caradoc. Llandeilo. Arenig.	
	CAMBRIAN.	{ Tremadoc. Lingula. Menevian. Harlech.	
ARCHÆAN.	{ PEBIDIAN AND URICONIAN ROCKS OF WALES. HEBRIDEAN ROCKS OF SCOTLAND.		{ EOOZOIC.

## CHAPTER X.

## PALÆONTOLOGY, OR THE SCIENCE OF FOSSILS.

156. BEFORE he enters upon the study of the fossiliferous systems, it is necessary to remind the student that the department of science having special reference to fossils is termed *Palæontology* (Gr. *palaaios*, ancient; *onta*, beings; and *logos*, a discourse), or that which treats of the ancient or former life of the globe; while the department more immediately concerned with the rocks and their physical relations is spoken of as *Petrology* (Gr. *petra*, and *logos*). The palæontological and petrological aspects of a system are therefore two very different things, and convey much the same meaning as when we speak of the *stratigraphical* order of its rocks, and the *zoological* or *botanical* characters of its fossils. A geologist may be well acquainted with the positions, structure, and composition of rocks, and yet, from want of skill in botany and zoology, may know little of fossil plants and animals. In describing the fossils of a system, the brief term *Flora* is usually employed to denote the general assemblage of its plants, while the term *Fauna* is applied to that of its animal remains. PLANTS are either *flowering* or *flowerless*—the former comprehending the true timber-trees, shrubs, pines, palms, canes, and grasses, and the latter the lowlier club-mosses, ferns, equisetums, mosses, lichens, liverworts, mushrooms, and sea-weeds; and that ANIMALS are either *vertebrate* (backboned) or *invertebrate*—the former comprising the mammals, birds, reptiles, and fishes; and the latter the shell-fish, crabs, insects, worms, star-fish, sea-urchins, corals, sponges, and other lowly organisms. In a fossil state the harder and more durable portions are usually best preserved; hence the perfection of corals, shells, scales, scutes, spines, teeth, and bones, among animal structures preserved as fossils—and trunks, branches, hard

fruits, and dry leathery leaves among fossil vegetables. Whatever the object preserved, there is either (*a*) the real *substance itself*, as in the case of the Siberian mammoth, fossil corals, and the like; (*b*) the substance *replaced* by some mineral matter, as in the case of silicified wood, &c.; (*c*) a *mould* of the organism, its material having been wholly removed; (*d*) a *cast* of the fossil, the mould having been filled up by some mineral matter, silica, carbonate of lime, or pyrites; or (*e*) it may be a mere *impression*, such as the footprint of a bird or the track of a worm. As plants are aquatic, palustral (Lat. *palus*, a marsh), and terrestrial—some flourishing in tropical, some in temperate, and others in Arctic regions; and as animals are also marine, fresh-water, or terrestrial—some peculiar to warm, some to temperate, and others to colder zones: so by a study of fossil remains the geologist can indicate the *conditions*—*marine*, *estuarine*, or *lacustrine*—in which they were entombed, and the nature of the *climate* under which they lived and grew.

157. The science of *Palæontology* is merely a branch of the great science of *Biology*, dealing with the animals and plants of past times as modern *Biology* deals with the life of the present. As the science of recent *Biology* falls into the two sections of *Zoology* and *Botany*—the former treating of present animals, and the latter of plants—so *Palæontology* is divided into *Palæozoology* and *Palæobotany*. But the life of the present is simply the extension and sequence of the life of the past, and the same laws of development and growth, the same principles of classification and study, are necessarily applicable to all organisms, living or extinct. Hence it is necessary that the student of *Geology* should have some acquaintance with such biological facts and conclusions as will enable him to classify his fossils in their proper biological order, and be able to appreciate the true relationship between the great life-types of the past and those which are now living upon the face of the globe.

#### CLASSIFICATION OF ANIMALS.

158. Animals have been arranged by zoologists into two grand divisions—*VERTEBRATA* (backboned), and *INVERTEBRATA*. Of these, the *Vertebrata* constitute a single sub-kingdom, while the *Invertebrata* are arranged into eight sub-kingdoms—viz., (8) *Mollusca* (Lat. *mollis*, soft), or soft-bodied animals, including the cuttle-fishes, oysters, and their

relations ; (7) *Molluscoida* (Gr. *eidos*, like), including the lamp-shells and sea-mats, &c. ; (6) *Articulata* (Lat. *articulus*, a little joint), including lobsters, insects, and other jointed animals ; (5) *Vermes*, or Worms ; (4) *Echinodermata* (Gr. *echinus*, a sea-urchin, and *derma*, skin), including the sea-urchins and starfish ; (3) *Cœlenterata* (Gr. *cœlus*, hollow ; *enteron*, intestine), including the corals and zoophytes generally ; (2) the *Spongida*, or Sponges ; and (1) *Protozoa* (Gr. *protos*, first), or animals of the lowest type, such as the Foraminifera and Infusoria.

159. Each of these sub-kingdoms is broken up into large divisions called *Classes* ; each class is broken up into *Orders* ; each order into *Families* ; and each family is composed of what are termed *Species*. Each species receives a distinctive name of its own, or rather two names, the first being the name of the genus to which it belongs, and the second the distinctive title of the species itself. Thus the common dog is known zoologically as *Canis familiaris*, the wolf as *Canis lupus*, the fox as *Canis* (or *Vulpes*) *vulgaris*. They all belong to the *genus* *Canis*, which is a genus of the *family* of the *Canidæ*, a family which belongs to the *order* of the *Carnivora*, which, in its turn, is one of the orders of the *class* of the *Mammalia*, one of the great classes which make up the *sub-kingdom* of the *Vertebrata*. Bearing this gradation in mind, the student will have little difficulty in understanding the following general classification of the Animal Kingdom, in which the extinct genera are given in italics :—

## SUB-KINGDOM I.—VERTEBRATA.

Animals typically possessing a backbone and bony skeleton.

CLASS A. MAMMALIA (*Sucklers*), divided into—

(I.) PLACENTAL (bringing forth mature young).

(II.) APLACENTAL (bringing forth immature young).

The latter are subdivided into (a) *Marsupialia*, pouched Mammals ; and (b) *Ornithodelphia*, egg-bearing Mammals.

### Section 1. PLACENTAL.

1. PRIMATES (*first*)—Including Man, Monkeys, and Lemurs.

2. INSECTIVORA (*Insect-eaters*)—Moles, Shrews, Hedgehogs, &c.

3. CHEIROPTERA (*Hand-winged*)—Including the various kinds of Bats, &c.

4. RODENTIA (*Gnawers*)—Hare, Beaver, Rat, Porcupine, &c.

5. CARNIVORA (*Flesh-eaters*)—Beasts of Prey, Dog, Wolf, Tiger, &c., &c.

6. UNGULATA (*Hoofed animals*), including :—

Division (a) PERISSODACTYLA. (*Odd-toed Ungulates*)—Rhinoceros, Tapir, Horse, &c.

Division (b) ARTIODACTYLA. (*Even-toed Ungulates*)—Including the Hippopotamus, Pigs, and the whole tribe of the Ruminants (*Cud-chewers*)—viz., Oxen, Sheep, Goats, Camels, &c.

Division (c) *The Elephants*. Sometimes erected into a distinct Order, the *Proboscidea*.

## 7. CETACEA—Whales, Dolphins, and Porpoises.

## 8. SIRENIA—Dugongs and Manatees (large vegetable-feeding, fish-like, aquatic Mammals).

9. EDENTATA (*Toothless*). A few have teeth, destitute, however, of true enamel. Sloths, Ant-eaters, Armadilloes, &c.

## Section 2. APLACENTAL.

10. MARSUPIALIA (*Pouched animals*)—Opossum, Kangaroo, &c.11. MONOTREMATA (*One-vented*)—Including egg-bearing Mammals,—Ornithorhynchus, and spiny Ant-eaters.

## CLASS B. AVES OR BIRDS.

## Section 1. CARINATÆ—Breast-bone keeled.

So called from the general form of the breast-bone. This class includes the majority of living birds, but zoologists are not yet agreed as to the extent and limit of the orders into which it should be divided. The following are the most important groups :—

1. RAPTORES (*Seizers*)—Eagles, Hawks, Falcons, Owls, and Vultures, &c.2. INSESSORES (*Perchers*)—Jays, Crows, Finches, Sparrows.3. SCANSORES (*Climbers*)—Woodpeckers, Parrots, Cuckoos, &c.4. COLUMBÆ (*Pigeons*)—Doves, Pigeons, *Dodo*.5. RASORES (*Scratchers*)—Barn-fowl, Partridge, Pheasant, &c.6. GRALLATORES (*Waders*)—Rails, Storks, Cranes, Herons, &c.7. NATATORES (*Swimmers*)—Divers, Gulls, Ducks, &c.

## Section 2. RATITÆ—Breast-bone raft-like.

8. CURSORES (*Runners*)—Ostrich, Rhea, Cassowary, Emu, &c.Section 3. ODONTORNITHES (*Toothed Birds*).

These are all extinct, and include the fossils *Hesperonis* and *Ichthyornis*.

Section 4. SAURURA (*Saurian-tailed*).

This class is also extinct, and is represented by the curious *Archæopteryx* of the Jurassic.

## CLASS C. REPTILIA.

Of these, only four orders survive; all the rest are extinct. Among these extinct forms are some that are intermediate in character between Birds and Reptiles.

## (a) EXTINCT ORDERS.

1. DEINOSAURIA (*Terrible Lizards*)—Gigantic Lizards intermediate between Birds and Reptiles. *Deinosaur*.
2. PTEROSAURIA (*Winged Lizards*)—*Pterodactylus*, *Ramphorhynchus*.
3. ICHTHYOSAURIA (*Fish-like Saurians*)—Gigantic Sea-lizards, *Ichthyosaurus*.
4. PLESIOSAURIA (*Long-necked Saurians*)—Allied to those of last Order, but having a long neck and short tail. *Plesiosaurus*.

## (b) LIVING ORDERS.

5. CHELONIA (*Turtles*)—Including Turtles, Tortoises, &c.
6. OPHIDIA (*Serpents*)—Including Vipers, Snakes, Boas, &c.
7. LACERTILIA (*Lizards*)—Iguana, Chameleon, Lizards.
8. CROCODYLIA (*Crocodiles*)—Alligator, Crocodile, Gavial.

## CLASS D. AMPHIBIA.

1. URODELA (*Tailed*)—Newts, Sirens, and Mud-eels.
2. ANOURA (*Tailless*)—Frogs and Toads.
3. OPHIOMORPHA (*Snake-like*)—Blind-worms.
4. LABYRINTHODONTA (*Labyrinthine-toothed*)—An extinct Order. *Labyrinthodon*.

## CLASS E. PISCES OR FISHES.

*Sub-Class 1. TELEOSTIA (Perfect-boned)*—Salmon, Perch, Trout, Herring, &c.

*Sub-Class 2. PALÆICHTHYES (Ancient Fishes)*—Including the sections:—

*Order 1. PLACOIDS OR ELASMOBRANCHS (Plate-gilled)*—Skin without scales, but furnished with projections or spines. Palate sometimes armed with flat crushing teeth (Chimeroids).

*Order 2. GANOIDS (Shining)*—Body covered with bony plates or shining scales. Nearly all extinct (*Cephalaspis*, *Gyrodus*).

*Order 3. DIPNOI* (including *Lepidosiren* and *Ceratodus*), which possess characteristics intermediate between those of Fishes and Amphibians.

*Sub-Class 3. CYCLOSTOMATA (Circle-mouthed)*—Lampreys, &c.

*Sub-Class 4. LEPTOCARDII (Slender-hearted)*—Amphioxus or Lancelet.

## SUB-KINGDOM II.—MOLLUSCA.

Soft-bodied animals, usually covered with hard calcareous shell.

CLASS I. CEPHALOPODA (*Head-footed*)—Cuttle-fishes, Octopus, Nautilus, &c. Divided into two sections—

*Section 1. TETRABRANCHIATA (Four-gilled)*—Nearly all extinct. Includes Nautilus, Ammonite, *Goniatite*.

*Section 2. DIBRANCHIATA (Two-gilled)*—Argonaut, Octopus, *Belemnite*, &c.

CLASS II. PTEROPODA (*Wing-footed*)—Headless Molluscs, with wing-like fins. Includes *Hyalea*, *Theca*, *Conularia*, &c.

CLASS III. GASTEROPODA (*Belly-footed*)—Snails, Limpets, Whelks, Cowries, &c.

CLASS IV. LAMELLIBRANCHIATA (*Leaf-gilled*)—Oyster, Mussel, Cockle, &c.

### SUB-KINGDOM III.—MOLLUSCOIDA.

Soft-bodied animals, usually of lower type than Mollusca proper.

A provisional group, its three classes being sometimes regarded as distinct sub-kingdoms.

CLASS I. TUNICATA (*Coated*)—Sea-squirts or Ascidians.

CLASS II. BRACHIOPODA (*Arm-footed*)—Lamp-shells—*Lingula*, *Terebratula*, *Spirifer*.

CLASS III. POLYZOA (*Compound Animals*)—Sea-mats and Sea-mosses, *Fenestella*, *Flustra*.

### SUB-KINGDOM IV.—ARTICULATA OR ARTHROPODA.

Animals protected by hard skin or covering, and having jointed limbs.

CLASS I. CRUSTACEA (*Crust-clad*)—Lobsters, Crabs, *Trilobites*, *Eurypterids*, &c.

CLASS II. ARACHNIDA (*Spiders*)—Scorpions, Spiders, &c.

CLASS III. MYRIADOPODA (*Many-footed*)—Centipedes, Galley-worms.

CLASS IV. INSECTA (*Insects*)—Beetles, Flies, Bees, Wasps, &c.

### SUB-KINGDOM V.—VERMES OR ANNULOSA.

CLASS I. SCOLECIDA (WORMS PROPER).

CLASS II. ANARTHROPODA (HIGHER WORMS).

The only order of geological importance is that of the Annelida.

### SUB-KINGDOM VI.—ECHINODERMATA (URCHIN-SKINNED).

Divided into two sub-classes—(a) PELMATOZOA (*Stemmed*), and  
(b) ECHINOZOA (*Stemless*).

#### SUB-CLASS I. PELMATOZOA.

Order 1. CRINOIDEA (*Encrinites*)—Sea-lilies, *Pentacrinus*.

„ 2. CYSTIDEANS (Extinct)—*Hemicosmites*.

„ 3. BLASTOIDS (Extinct)—*Pentremites*.

## SUB-CLASS II. ECHINOZOA.

- Order 4. ECHINOIDEA (*Sea-urchins*)—Echinus, Cidaris.  
 „ 5. ASTEROIDEA (*Star-fishes*)—Asteria.  
 „ 6. HOLOTHUROIDEA (*Sea-cucumbers*)—Trepang.

## SUB-KINGDOM VII.—CŒLEENTERATA.

CLASS I. ACTINOZOA (*Rayed*)—Arranged in 4 Orders :—

- Order 1. ZOANTHARIA (*True Corals*)—Corals with 6 rays, Sea-anemones, Reef Corals, &c.  
 „ 2. RUGOSA (*Rough Corals*)—Corals with 4 rays.  
 „ 3. ALCYONARIA (*Sea-pens*)—Corals with 8 rays. Pennatula, &c.  
 „ 4. CTENOPHORA (*Comb-bearers*)—Medusiform Actinozoa, transparent forms. Venus's Girdle.

CLASS II. HYDROZOA (*Hydra-like*).

## Sub-Class 1. HYDROIDA—Common Hydra, &amp;c.

- Order 1. ATHECATA (*Sheathless*)—Corynoida, &c.  
 „ 2. THECOPHORA (*Sheath-bearing*)—Sertularia, Campanularia.  
 „ 3. GRAPTOLITHINA—Extinct Zoophytes allied to the Thecophora.  
 „ 4. MEDUSÆ (*Jelly-fishes*).

## Sub-Class 2. SIPHONOPHORA or OCEANIC HYDROZOA.

- Order 1. CALYCOPHORIDÆ.  
 „ 2. PHYSOPHORIDÆ.  
 „ 3. LUCERNARIDA.

## SUB-KINGDOM VIII.—PORIFERA or SPONGIDA.

These are divided into several groups dependent upon the composition or form of their spicules.

- Section I. CALCISPONGIA (*Calcareous Sponges*).  
 „ II. LITHISTIDÆ (*Stony Sponges*).  
 „ III. HEXACTINELLIDÆ (*Six-rayed Sponges*).  
 „ IV. CERATOSPONGIDÆ (*Horny Sponges*).

## SUB-KINGDOM IX.—PROTOZOA (LOWEST LIFE).

Of these only one class—RHIZOPODA—and of this class only two orders—viz., (a) FORAMINIFERA (*Calcareous Rhizopoda*), and (b) RADIOLARIA (*Siliceous Rhizopoda*)—are of geological importance. Both, especially the Foraminifera, occur in abundance in the modern deep-sea oozes, and in various geological formations.

## CLASSIFICATION OF PLANTS.

160. Plants have been arranged by botanists into two grand divisions — PHANEROGAMS or *flowering plants*, and CRYPTO-GAMS or *flowerless plants*.

DIVISION I.—PHANEROGAMIA (FLOWERING PLANTS) or  
SPERMOPHYTA (SEED-PLANTS).

SECTION A. ANGIOSPERMS (Gr. *anggeion*, a vessel; *sperma*, seed), plants having their seeds enclosed in an ovary.

*Class I. DICOTYLEDONS* (Gr. *dis*, twice), plants with two *cotyledons* or seed-lobes. Also called EXOGENS, from their mode of growth—annual increase by *external* layers of new material. This class embraces all the most highly organised groups of plants, and includes most of our forest-trees and shrubs. The various divisions and subdivisions of the class are too numerous to be here referred to. Some of the most remarkable orders are:—

*Order 1. URTICACEÆ*—Nettles.

" 2. LAURINÆ—Laurels.

" 3. PAPILIONACEÆ—Peas and Beans.

" 4. ERICACEÆ—Heaths.

" 5. ROSACEÆ—Roses.

" 6. CRUCIFERÆ—Plants with cross-shaped flowers.

" 7. COMPOSITÆ—Plants with compound flowers.

&c. &c.

*Class II. MONOCOTYLEDONS* (Gr. *monos*, one), plants having one cotyledon; known also as ENDOGENS, from their characteristic mode of growth, increasing by additions in *interior*. They embrace the following orders or divisions among many others:—

*Order 1. PALMACEÆ*—Palms.

" 2. PANDANACEÆ—Screw-pines.

" 3. GRAMINEÆ—Grasses.

" 4. ORCHIDEÆ—Orchids.

&c. &c.

SECTION B. GYMNOSPERMS (Gr. *gumnos*, naked; *sperma*, seed), plants with naked seeds—*i.e.*, not enclosed in an ovary.

*Order 1. GNETACEÆ*—Joint Firs, &c.

" 2. CONIFERÆ—Pines, Firs, and Cypresses.

" 3. CYCADEÆ—Cycads, plants related to ferns and palms.

DIVISION II. — CRYPTOGAMS (FLOWERLESS PLANTS) (Gr. *cryptos*, concealed; *gamos*, union). Plants bearing spores instead of seed (SPOROPHYTES). They embrace the following primary groups:—

CLASS I. PTERIDOPHYTES (Fern-plants). (Gr. *pteron*, a wing or fern ;  
*phyton*, a plant.)

Order 1. LYCOPODIACEÆ, Club-mosses, Lycopods, &c.

" 2. EQUISETACEÆ—Horse-tails, *Calamites*.

" 3. FILICES—Ferns proper.

CLASS II. BRYOPHYTES (Moss-plants). (Gr. *bruon*, moss.)

Order 1. MUSCINÆ—Mosses.

" 2. HEPATICÆ—Liverworts.

CLASS III. THALLOPHYTES (plants having no distinction of root, stem,  
and leaves).

Order 1. FUNGI—Mushrooms, &c.

" 2. ALGÆ—Sea-weeds.

" 3. PROTOPHYTES—Lowest plants—Yeast-plant, &c.

## SECTION I.—EOZOIC PERIOD.

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### CHAPTER XI.

#### THE ARCHÆAN OR PRE-CAMBRIAN ROCKS.

161. As stated in the preceding chapter, the term Archæan is employed as a collective title for the whole of those more or less metamorphic and altered rocks which underlie the lowest of the unequivocally stratified and fossiliferous systems. The Archæan rocks are mostly buried from sight in Britain below these overlying accumulations; but where the latter have been wholly removed by denudation, as in Scandinavia and British North America, the fundamental rocks are laid bare over large areas of the earth's surface. The majority of these Archæan rocks are highly metamorphosed, are foliated, schistose, and distinctly crystalline. But in some areas they have been but little altered, and they approximate in their lithological and physical characters to the ordinary rocks of the typical fossiliferous systems. Where they are foliated, the Archæan rocks are made up of layers of coarsely crystalline gneisses and more finely crystalline schists, intermixed with subordinate bands of hornblendic and pyroxenic rocks, sheets of marble, dolomite, serpentine, and schistose quartzite. In the areas where they are non-foliated we find them composed of slates, of igneous rocks, both contemporaneous and intrusive, of masses of barren sandstone and grit, of altered limestones, quartzites, and even boulder conglomerates.

162. The Archæan rocks were first studied with success in British North America, and this region is still regarded as the area in which the component groups appear to be most clearly defined. In Canada they clearly rise out from under-

neath the basal members of the Cambrian (the most ancient of the clearly-defined fossiliferous systems), whose oldest local beds rest unconformably upon them, and are in part composed of their weathered fragments. By their first investigator and describer, Sir W. Logan, these Archæan rocks of Canada were arranged into two main divisions—a lower division or *Laurentian* (so called from its occurrence in the Laurentide Mountains of Canada), and an upper division or *Huronian* (from Lake Huron, on the shores of which this division is best developed). Neither the base nor summit of the great Canadian Archæan series is visible; but looking upon the whole as essentially a sequence of stratified rocks, Logan showed that the upper division appeared to rest unconformably upon the lower, and that it was possible to arrive at an approximation to the total visible thickness of each. To the Laurentian he assigned a thickness of about 30,000 feet, and showed that it consisted in its lower portions of granites, orthoclase-gneisses, quartzites, and crystalline limestones; and in its upper part of gneisses, schists, and bands of iron ore. To the Huronian a thickness of about 10,000 feet was assigned, and it was defined as composed essentially of slates, conglomerates, limestones, and quartz rocks. Subsequent investigators have added largely to our knowledge of the Archæan rocks of America, and have proposed many additional divisions, but their views have not yet met with such wide and general acceptance as those first propounded by Sir W. Logan.

163. In rocks that have undergone so much change in structure and texture as those of the Archæan rocks of Canada, fossil remains are hardly to be expected—the metamorphism that induced the crystalline character of the foliated rocks being sufficient to obliterate every trace of organic existence. Although no fossils have yet been quoted even from the less altered Huronian rocks, yet from the more ancient limestones of the Laurentian series some remarkable structures have been obtained, which have been claimed by some of our chief palæontological authorities as being of organic origin. These structures occur in sheets and coral-like masses in the thick Laurentian limestones of central Canada. They consist usually of calcite and serpentine arranged in undulating layers, the calcite forming the main mass of the fossil, and the serpentinous matter filling up sub-regular wrinkles, hollows, and cavities between. By Sir J. W. Dawson of Montreal (whose views were subsequently confirmed by the late Dr W. B. Car-

penter of London), these structures were described as corresponding to those characteristic of certain forms of modern *Foraminifera*—organisms belonging to the *Protozoa* or lowest

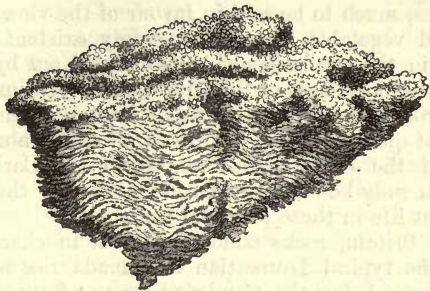


Fig. 59.—Weathered specimen of *Eozoön* (after Dawson), showing general form, with acervuline portion above and laminated below.

forms of animal life. He claimed the structure, therefore, as a true fossil, and named it *Eozoön Canadense* (or Dawn animal of Canada). On the ground of this discovery, the Lau-

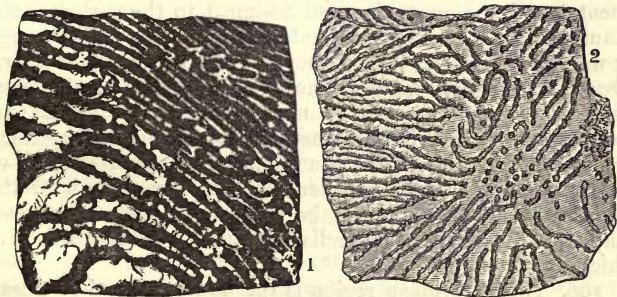


Fig. 60.—*Eozoön Canadense*. 1, *The Layers*, natural size; 2, *The Tubuli*, magnified 100 diameters (Carpenter).

rentian series of Canada has been regarded as an independent geological system, and the Archæan age erected into a distinct life-period, under the title of *Eozoic* (*eos*, dawn; *zoe*, life).

164. Although bodies similar in many respects to *Eozoön Canadense* have been detected in the Archæan rocks of Europe (in Bavaria, &c.), the organic nature of *Eozoön* has been strenuously denied by many investigators, and at the present

day the preponderance of scientific opinion appears to be in favour of regarding it merely as a peculiar mineral structure, mimetic or imitative of the organic. But even though the organic origin of Eozoön should fail to be established, there is, nevertheless, much to be said in favour of the view that both animal and vegetable life were certainly existent and even abundant in the Archæan age. As pointed out by Sir Wm. Dawson, the presence of massive sheets of limestone in Archæan rocks, as thick as those of later geological formation, and of quantities of graphite to an extent almost equal to that of the carbonaceous matter in the Carboniferous system, can only be naturally accounted for by the presence of abundant life in those primeval times.

165. In Britain, rocks almost identical in character with those of the typical Laurentian of Canada rise out unconformably from below the Cambrian strata of the north-west of Scotland. They occur in irregular areas on the mainland between Cape Wrath and Loch Maree, east of the Cambrian rocks, and constitute the whole of the island chain of the Outer Hebrides (Lewis, &c.), while other patches occur farther inland—in Sutherland, Ross, and elsewhere. These basal rocks were originally classed by Murchison as the Fundamental or *Lewisian* gneiss, and assigned to the period of the Laurentian. By later investigators, while their Archæan age is universally acknowledged, they are usually known as *Hebridean*. They consist mainly of hornblendic gneisses and schists, with subordinate patches of mica schist, actinolite schists, and crystalline limestone. They are locally pierced by thick veins of pegmatite (giant granite), and dykes of dolerite or basalt. As in Canada, neither the base nor summit of the series is visible, and as all the rocks are schistose, it seems impossible to arrive at any reliable estimate of their collective thickness.

166. This Hebridean region is the largest area of Archæan rocks yet recognised in Britain, but several minor areas of more or less crystalline rocks, which appear to be of pre-Cambrian age, occur within the limits of the British Islands. One of the most important is found in Pembrokeshire, in the neighbourhood of St David's. Here a thick series of crystalline rocks rises out from below the oldest fossiliferous Cambrian of that region. Its discoverer, Dr H. Hicks, regarded this series as composed of three distinct groups—(a) a lower (or *Dimetian*) group, consisting essentially of granitoid rocks; (b) a middle group (*Arvonian*), composed of quartz-felsites

and halleffintas; and (c) an upper group (*Pebidian*), made up of schists, slates, and volcanic breccias. By Dr A. Geikie, the lower and middle groups are held to be formed of intrusive rocks, while the *Pebidian* is regarded as forming the natural base of the Cambrian. The core of the Malvern Hills is composed of crystalline rocks, syenites, and hornblendic gneisses, &c., which rise up from below the Cambrian, and have consequently been classed by Dr Holl and others as Archæan. Igneous rocks, somewhat similar in character and position to the *Pebidian* of St David's, have been described as rising out from below the local Cambrian in the hills of *Caer Caradoc* and the *Wrekin*, by Dr C. Callaway, and have been entitled *Uriconian*. Corresponding rocks occur also in the centre of England in the area of *Charnwood Forest*, *Leicestershire*. Finally, the metamorphic regions of the central Highlands of Scotland, of N.-W. Ireland, of *Anglesea*, and of S.-W. Cornwall, may also include areas of Archæan rocks, but in no case has this yet been satisfactorily demonstrated.

167. Crystalline rocks, many of which are distinctly of pre-Cambrian or Archæan age, are largely developed upon the continent of Europe. They floor much of the peninsula of Scandinavia, and of N.-W. Russia, clearly rising out from below the oldest Cambrian of those regions. They are met with also in Bohemia and in Bavaria in similar relationships. Other bands protrude through the central parts of the chief mountain areas of Southern and Western Europe—in the Alps, the Pyrenees, the Cevennes, and the ranges of Brittany, &c. In India, Africa, and in South America, Archæan rocks are also found largely developed.

168. Of the actual *mode of origin* of the vast majority of the Archæan rocks, very little is yet known with certainty. Where they are comparatively unaltered, as in *Charnwood* and the *Wrekin*, &c., we can recognise the planes of their original stratification, and can study and classify them by the same general rules as those we employ in the investigation of fossiliferous systems. But in the case of the schistose and foliated rocks, of which the main masses of the Archæan areas are often composed, the case is wholly different, and we find ourselves face to face with what have hitherto proved to be insurmountable difficulties. Until within the last few years many geologists regarded the layers of these foliated rocks as relics of original sedimentation. By some theorists the whole of the Archæan rocks were looked upon as the primi-

tive or first-formed strata laid down upon the cooling earth crust, and their crystalline nature and non-fossiliferous characters were consequently regarded as resulting naturally from the peculiar conditions of the period in which they were deposited. By others they were held to be merely pre-Cambrian sediments, originally fossiliferous, and similar in lithological characters to those of later formations, altered into crystalline rocks by some obscure process of metamorphism, which left unmodified the original planes of stratification. So long as these views were held, it appeared possible to break up the Archæan into formations and systems by the same rules as those which apply to the fossiliferous rocks. But the recent discoveries in areas of regional metamorphism have rendered these apparently simple ideas no longer tenable. Many of the Archæan gneisses and schists are practically identical with those which have been formed in later times from intrusive igneous rocks by earth-pressure or dynamo-metamorphism; and the association of altered and unaltered crystalline and sedimentary rocks in a so-called Archæan system, agrees precisely with that of a mountain region whose bedded and intruded rocks, originally distinct, have been crushed into a common dip and strike by crust-movement. In this latter case we have learnt that the present apparent sequence of the rocks is delusive, and that the general foliation has little or no relation to the original bedding. As most of the foliated Archæan rocks occur in areas of regional metamorphism, it may be regarded as tolerably certain that they owe their schistose characters to the same agency, and that we are not dealing in a series of such foliated rocks with rock-systems, but with petrological complexes. That there were many British fossiliferous systems laid down in pre-Cambrian times is probable, but as yet not one has been recognised and established with certainty. Various theoretical assumptions have been made to overcome or elude the grave stratigraphical difficulties due to the widespread metamorphism of the Archæan rocks. By some the presumed Archæan systems have been confidently paralleled by their mineralogical characters; by others they have been roughly grouped, according to the relative degree of coarseness of the crystals of their schists and gneisses, or according to their comparative degree of metamorphism and the like. But not one of these principles could be safely relied upon even in the stratigraphy of the fossiliferous rocks, the sequence of which has been made out painfully and carefully in the field—by working out their

*original structures*, and by demonstrating the original positions and relationships of each of their various members beyond doubt or cavil; and nothing short of this can ever be satisfactory in the stratigraphy of the Archæan. But hitherto the actual work performed among these ancient rocks has been so insignificant compared with that which has been accomplished among the fossil-bearing formations, while the difficulties which confront us are so much more formidable, that there can be no surprise at the vagueness and uncertainty of our present knowledge of the Archæan rocks. We must wait for future discovery to determine for us what was their true mode of origin, their original sequence, and their most natural classification.

169. The regions occupied by the so-called Archæan rocks are either the cores of mountain-ranges, where their gneisses and schistose layers constitute some of the grandest scenery of the globe; or they are found, as in Canada and North America, forming broad expanses, here rising into broad rounded hill-ranges, there spreading out in wide rugged plains, dotted with countless lakes and tarns. The industrial products of Archæan areas are both numerous and important. Magnetic iron occurs in vast quantities in these rocks in North America and in Scandinavia; ornamental granite, serpentine, and marbles are also obtained. Important veins of silver, copper, and other precious metals occur in both European and American Archæan rocks. In Britain, however, they are comparatively poor in workable minerals, with the exception of marble and serpentine.

#### RECAPITULATION.

170. In this chapter we have glanced briefly at the state of our present knowledge of the distribution and physical characters of the so-called Archæan or pre-Cambrian rocks of the globe that probably everywhere underlie the fossiliferous systems, but which are only laid bare in a few small areas in Britain. We find them best developed on the continent of North America, where they consist of an enormous thickness of gneisses and schistose and altered rocks, upon which the lowest beds of the Cambrian rest unconformably. They were divided by their first describer into two series—a lower and gneissic series, the *Laurentian*; and an upper or slaty and less altered series, the *Huronian*. The detection of the curious fossil *Eozoön Canadense*, led to the provisional erection of

these two series into independent systems, and to the alteration of the title of the pre-Cambrian period from Azoic (lifeless) to Eozoic (dawn of life). In Britain, gneissic rocks, resembling those of the Laurentian of Canada, occur in North-west Scotland (*Hebridean*), in the Malvern Hills (*Malvernian*), &c. At St David's unaltered pre-Cambrian volcanic rocks (*Pebidian*) are met with, in the Wrekin (*Urconian*) and in Charnwood Forest, which may be collectively paralleled with the Huronian. But while it is the common practice among geologists to speak of the gneissic and more highly metamorphic Archæan rocks as the deeper and older, and the clearly stratified and little altered as the higher and younger, the student should be warned that this is done provisionally, simply as a matter of convenience of description. The unaltered Archæan rocks are largely formed of igneous material, both stratified and intrusive, and the altered or schistose rocks may have been formed by dynamo-metamorphism out of similar materials. As their present foliation has probably little or no relation to their original bedding, it has, as yet, been found impossible to give a reliable account of their true thickness, the natural order of their correspondent rock-sheets, or of their original relationships. The names given to the various so-called systems have merely a local value, and we must wait for future discovery to overcome the many difficulties which have hitherto proved insurmountable in the study of these fundamental rocks.

## SECTION II.—PROTEROZOIC PERIOD.

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### CHAPTER XII.

#### CAMBRIAN SYSTEM.

##### GENERAL CHARACTERS OF THE LOWER PALÆOZOIC OR PROTEROZOIC ROCKS.

171. RESTING at once upon the fundamental rocks which are classed as Archæan, and in most cases with a distinct unconformability, we find that vast thickness of stratified deposits which constitute the Primary, Palæozoic, or older half of the chronological scale of British formations. In the Archæan rocks, as we have seen, a crystalline aspect pervades almost the whole series, and it is only in those rare cases where foliation is absent that we can find reliable evidences of sedimentation, and are able to determine with certainty what parts are of aqueous and what of igneous origin, and what structures are original and what of secondary nature. But in the majority of the Palæozoic rocks these grave difficulties are absent, and if we except those few districts where they have been subjected to regional metamorphism, each stratum and alternation of strata is for the most part distinctly traceable, and, by the exercise of ordinary care, we are able to work out successfully the natural order of the various beds, and arrange them in series, formations, and systems. Beds of flaggy sandstone, pebbly conglomerate, shaly mudstone, and limestone, follow one another in frequent succession, and present so slight a change in their mineral structure and texture, that we can readily judge of the conditions under which they were deposited. Some of the sand-

stones are finely laminated, and bear evidence of tranquil sedimentation; others are ripple-marked, and testify to the presence of tides or gentle currents; some are marked by the

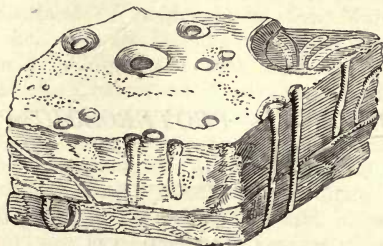


Fig. 61.—Worm-burrows (*Scolithus linearis*) in sandstone.

trails or pierced by the burrows of sand-worms; while others are pebbly conglomerates, and bespeak the existence of waves and gravel beaches, such as we witness at the present day. Of the shales or argillaceous beds, some have evidently been thrown down in deep water as soft black mud; while others have been formed in shallower bays, and contain a certain admixture of sand with sea-shells, such as now are found at no great depth from the shore. Of the limestones or calcareous strata, many are replete with the remains of corals and shells, and recall the existence of seas in which the coral-polype reared its reefs, and shell-fish congregated in beds like the oyster and mussel of our own times. Indeed, the abundant presence of zoophytes, corals, molluscs, and crustaceans, tells of varying conditions of water and sea-bottom, of light and heat, of tribes that obtained their nutriment from the ocean or preyed on each other; and, generally, of a state of things analogous to that now going on along the shores, on the shoals, and in the deeper waters of existing seas.

172. The Palæozoic rocks fall very naturally in Britain into two main subdivisions—an earlier or Lower Palæozoic, and a later or Upper Palæozoic subdivision. For the period in which the Lower Palæozoic rocks were laid down the name *Proterozoic* (Gr. *proteros*, the earlier, first), or *earlier life*, has been proposed, and to the Upper Palæozoic the title of *Deuterozoic* (Gr. *deuteros*, second), or second life. The rocks laid down in the Proterozoic or Lower Palæozoic period, in our area, are all marine, and afford us no traces of land-plants or land-animals. The strata laid down in the Deuterozoic period, on the con-

trary, are mainly lacustrine or estuarine, and afford the richest collection of land-plants and fresh-water animals known in our British rocks. Not only do our Proterozoic and Deuterozoic rocks thus differ broadly as regards their mode and place of origin and the facies of their organic remains, but they are as strikingly contrasted in the peculiar lithological features of their component strata. The Deuterozoic rocks are made up of coarse red sandstones and grits, limestones, beds of intensely black coals, and brightly-coloured shales and clays. The Proterozoic systems, on the other hand, are almost wholly made up of repetitions of dull greyish-green greywackès, flagstones, mudstones, and shales; such limestones and brightly-coloured sandstones, &c., as occur, are comparatively rare. By the older geologists the Proterozoic rocks were collectively known as the *Greywackè* or *Grauwackè* formations, from their characteristic rock type; or *Transitional*, from the fact that they are intermediate, both in systematic position and characteristic features, between the altered, crystalline, and barren fundamental or Archæan series below, and the unaltered, distinctly stratified, and richly fossiliferous Deuterozoic rocks above.

173. The Proterozoic rocks occur in most of the chief mountain areas of the British Isles, in Wales and the West of England, in the Lake District, South Scotland, and in the counties of Wicklow, Kerry, Galway, and Down, in Ireland. In all these areas they are more or less upheaved, contorted, and broken, and in some cases their shales have been cleaved into slates. In the British areas of regional metamorphism—viz., in the Scottish Highlands and North-west Ireland—it is held by some that many of the local gneisses and schists have been formed from Proterozoic rocks; but this is not yet demonstrated.

174. In the unaltered regions fossils have been met with from base to summit of the Proterozoic rocks—rarely, however, in such abundance as in the later formations. Broadly speaking, these fossils all belong to the Invertèbrata of zoologists, all the sub-kingdoms of which are represented, but in very different degrees. Examples of the first Vertebrata (fishes) occur only in their highest rocks.

175. It is universally admitted that the Proterozoic rocks are most naturally arranged in *three* main divisions or *systems*: and as these rocks are typically developed in Wales, the names we apply to the three systems are derived from that region. The lowest system or division is known as *Cambrian* (from *Cambria*, the ancient name of Western Wales); the middle as

*Ordovician* (from the *Ordovices*, the ancient inhabitants of North Wales); and the highest as *Silurian* (from the *Silures*, the ancient people of South Wales). This simple nomenclature, however, is not yet universally adopted. Some geologists prefer to regard the whole of the Proterozoic rocks as constituting one gigantic system, equivalent to the ancient Greywackè or Transition, employing for it the collective title of *Silurian* (Murchison), and naming its three grand divisions Primordial, Lower, and Upper Silurian. Others retain the

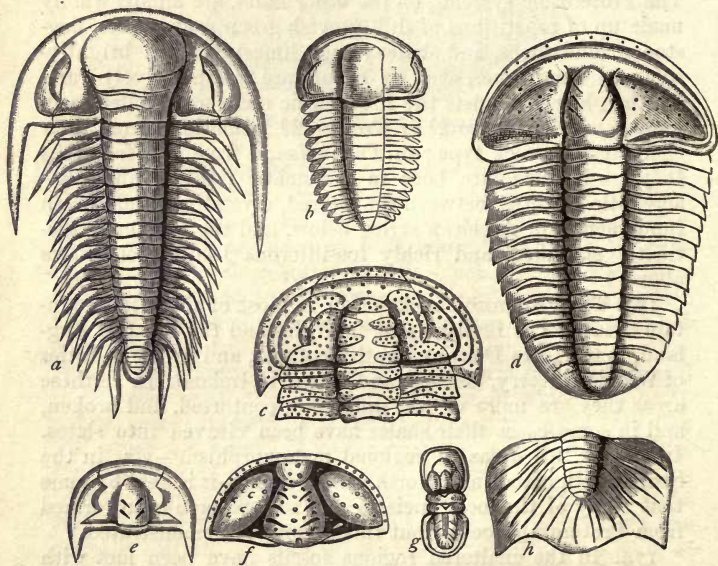


Fig. 62.—Lower Cambrian Trilobites: *a*, *Paradoxides Bohemicus*; *b*, *Ellipsocephalus Hoffii*; *c*, *Sao hirsuta*; *d*, *Conocoryphe Sultzeri*; *e*, *Agnostus rex* (from Lower Cambrian Rocks of Bohemia); *f*, *Conocoryphe Matthewi* (Acadian of N. America). Upper Cambrian forms: *e*, *Dicellosephalus Celticus* (Lingula Flags); *h*, *Dicellosephalus Minnesotensis* (Potsdam Sandstone). (H. A. Nicholson.)

original arrangement proposed by Professor Sedgwick, who classed the lower and middle divisions as *Cambrian*, and restricted the use of *Silurian* to the highest division alone. Others term the middle system *Cambro-Silurian*. Others, again, apply the name of *Cambrian* to the lowest system alone, and class both the middle and upper as *Silurian*. The simple and natural plan of using for each of the three component

systems of the Proterozoic its own special and distinctive name is followed here, and is certain to be eventually adopted in fact, as it is now accepted in principle, by all geologists.

## CAMBRIAN SYSTEM.

176. The rocks of the Cambrian or oldest fossiliferous system occur in several areas in Wales and in the west and centre of England. In the neighbourhood of St David's and N.-W. Scotland, its lowest beds are seen resting at once on the local Archæan, and in some localities its highest strata rises out visibly from below the conformably overlying strata of the Ordovician. The total thickness of the system in Britain is as yet unsettled, but it has been variously estimated at from 10,000 to 20,000 feet. It is naturally separable into two main divisions—(a) *Lower*, and (b) *Upper Cambrian*—and each of these falls into several distinct formations.

177. The life of Cambrian times included examples of all the

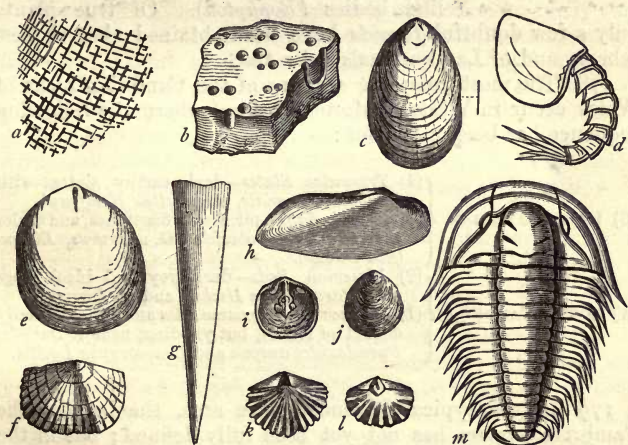


Fig. 63.—Lower Cambrian: a, *Protospongia fenestrata*; b, *Arenicolites didymus*; c, *Lingulella ferruginea*; h, *Modiolopsis Solvensis*; k, *Orthis Hicksii*; i, *Obolella sagittalis* (Harlech and Menevian Beds). Upper Cambrian: d, *Hymenocaris vermicauda*; f, *Orthis lenticularis*; g, *Theca Davisii*; m, *Olenus micrurus* (Lingula Flags and Tremadoc Slates). (Nicholson.)

sub-kingdoms of the *Invertebrata*. The commonest and most characteristic fossils are certain forms of an extinct order of Crustacea known as *Trilobites* (from their trilobed form). Of

these, the chief Cambrian genera are *Paradoxides* of the Lower Cambrian, *Olenus* of the Upper Cambrian, and *Agnostus*, which ranges upwards also into the Ordovician. Mollusca



Fig. 64.—Fragment of *Dictyonema sociale*, magnified (Tremadoc).

occur of several classes,—i.e., Cephalopods (*Orthoceras*, *Cyrtoceras*); Gasteropods (*Bellerophon*, *Maclurea*); Pteropods (*Theca* or *Hyolithes*); Lamellibranchs (*Ctenodonta*, *Modiolopsis*). Of Molluscoida the only forms known are certain genera of Brachiopoda (*Orthis*, *Lingulella*, and *Obolella*). Echinoderms are represented by *Star-fish* and *Encrinites*. Of Zoophytes (Cœlenterata) we have *Dictyonema*, a net-like graptolite occurring in the highest beds of the system, and the doubtful *Oldhamia* in beds referred to the lower division. Sponges are rare (*Protospongia*), and to this group may possibly be referred certain Cambrian plant-like bodies (*Eophyton*). Of true plants

only a few doubtful *fucoids* have been obtained; but of Vertebrata and of Land animals not a trace.

178. The most complete sections of the Cambrian rocks of Wales occur in Western Merionethshire, where the following sequence has been made out:—

- |                    |   |
|--------------------|---|
| (B) UPPER CAMBRIAN | { (4) <i>Tremadoc Slates</i> —dark earthy slates with <i>Dictyonema sociale</i> , <i>Asaphellus Homfrayi</i> .<br>(3) <i>Lingula flags</i> —micaceous flagstones, and shales with <i>Olenus scarabeoides</i> , <i>O. micrurus</i> , <i>Lingulella Davisii</i> .                         |
| (A) LOWER CAMBRIAN | { (2) <i>Menevian Beds</i> —dark-grey and black flags with <i>Paradoxides Hicksii</i> and <i>P. Davisii</i> .<br>(1) <i>Harlech Beds</i> —coarse grits and slates, usually devoid of fossils, but yielding, near St David's, <i>Paradoxides aurora</i> and <i>Conocoryphe Lyellii</i> . |

179. In the typical Merionethshire area, the base of the Cambrian system has not yet been fully defined; but in the neighbourhood of St David's, its basal beds repose on the igneous rocks of the Pebidian. Strata resembling the Harlech rocks rise out from below the Ordovician in central Shropshire, forming the barren tract of the Longmynd. The barren purple grit and conglomerate of Torridon, in N.-W. Scotland, which rests unconformably upon the Hebridean, and is covered up unconformably above by the fossil-bearing Assynt rocks, has been referred to the Lower Cambrian

period, and also the *Oldhamia*-bearing grits and flagstones of Wicklow in Ireland.

180. In Merionethshire, Pembroke, and Caernarvon, the Upper Cambrian reposes conformably upon the lower member of the system, and resembles it generally in lithological character. Elsewhere, however, the Upper Cambrian appears to be of a very different petrological character, and to rest often upon rocks which have been looked upon as of pre-Cambrian age. The largest exposure of these Upper Cambrian rocks occurs in the Nuneaton area of E. Warwickshire, where the basal *Quartzite*, the *Olenus*-bearing and *Dictyonema* beds are well exhibited. A second exposure is seen in Central Shropshire, showing the quartzite, Hollybush sandstone, and Tremadoc beds. In the Malvern Hills the quartzite is absent, but the Hollybush sandstone, *Olenus* beds, and *Dictyonema* shales are all present, and more or less fossiliferous. A smaller exposure of the quartzite alone forms the Lower Lickey Hills of Worcestershire.

181. In the North-west Highlands of Scotland a fairly continuous band of fossil-bearing Lower Palæozoic rocks ranges from the shores of Loch Eriboll through the counties of Sutherland, Ross, and Inverness to the southern extremity of the isle of Skye, resting unconformably upon the Hebridean gneisses and Torridon sandstone below, and covered up above by the *overthrust* masses of metamorphic rock (Eastern Gneiss) of the more central Highlands. It consists of the following members, in descending order:—

*Durness Limestone*—a massive limestone of great thickness, containing examples of the genera *Piloceras*, *Maclurea*, *Orthoceras*, &c.

*Salterella Quartzite*—a thin band of quartzite, with small Pteropod or Annelide tubes (*Salterella Macullockii*).

*Fucoid Beds*—hard flagstones and shales, with trails and burrows of Annelides, the *fucoids* or sea-weeds of some authorities.

*Eriboll Quartzite*—A massive pale quartzite, resting unconformably upon the rocks below.

The Eriboll quartzite reminds us greatly of the Nuneaton quartzite of Southern Britain, of which it may possibly be the northern extension. The fauna of the Durness limestone also is very similar to that of the Calciferous group, the highest Cambrian formation of North America. On the other hand, it shows a certain relationship to the *Orthoceras* limestone group of Scandinavia, the lowest Ordovician limestone of that

region, so that its Upper Cambrian age cannot be regarded as fully established.

182. The Cambrian rocks of the continent of Europe occur at many scattered localities along a line ranging from the island of Sardinia across Spain, Belgium, Scandinavia, to Esthonia ; and also in the central parts of the Continent, in Bohemia and Thuringia. In the Bohemia region, as in some parts of Britain, the Lower Cambrian with *Paradoxides* is separated from the beds above by a great unconformity. In Scandinavia and Russia, the two divisions are conformable, and in the former region are magnificently developed as regards their abundant fossils, but are of very insignificant thickness. In Belgium the *Dictyonema* beds of the Upper Cambrian occur ; and in Spain and Sardinia the *Paradoxides* beds of the Lower Cambrian. On the continent of North America both divisions are apparent—the lower division (*Acadian*) resting at once on the Archæan rocks, and yielding the usual *Paradoxides* in New Brunswick, New York, and allied forms in the Rocky Mountains. The upper division is formed of a siliceous sandstone in its lower part (*Potsdam sandstone*), and of a calcareous zone above (*Calciferosus sand-rock*). These contain the usual genera *Olenus* and *Agnostus*, &c., and can be traced from Alabama to Newfoundland, and from New York into Texas.

183. As an industrial repository, the Cambrian yields slates of unrivalled quality (Llanberis), and occasionally ores of iron, silver, and gold (Dolgelly). Indeed it is chiefly in the earlier geological formations, the Archæan and the Proterozoic, that the richest metalliferous veins occur, nature having had longest time, as it were, to elaborate these ores from the aqueous solutions percolating the chinks and fissures of the earth crust. It is in such regions of these ancient rocks, rugged and inhospitable as they may be, that the mining industry of the world is chiefly situated—their subterranean wealth compensating for their want of agricultural amenity and fertility.

#### RECAPITULATION.

184. The Palæozoic or Primary half of the fossiliferous rocks of Britain is divisible into two main sections, distinguished by the lithological character of their strata, their manner and place of disposition, and the general character of their included fossils. The Lower Palæozoic rocks are typically formed of an enormous succession of greywackes, flag-

stones, and shales of a dull grey or greenish colour; and their fossils are all marine, and appertain almost exclusively to the great division of the Invertebrata. The Upper Palæozoic rocks are of a very varied character—sandstones, conglomerates, limestones, and coals; they are largely of lacustrine, estuarine, or shallow-water origin; their fossils include plants in great abundance, and animal forms characteristic of fresh-water and estuarine conditions. The Lower Palæozoic period, originally known as the *Greywackè* or *Transitional* period, has been more recently distinguished as the *Proterozoic* or period of early life; the Upper Palæozoic as the *Deuterozoic* or age of second life. The rocks of the Proterozoic period are divisible into three main systems: the *Cambrian*, *Ordovician*, and *Silurian*, the names of which are derived from the typical districts of Wales and the West of England.

185. The first of these systems (*Cambrian*) is separable into a lower and an upper division, the former being composed of the *Harlech* and *Menevian* formations, and the latter of the *Lingula flags* and *Tremadoc slates*. The fossils of the Cambrian system include examples of all the invertebrate subkingdoms, the family of *Trilobites* constituting the most prevalent and characteristic forms in the British Cambrian rocks. Of these, the genus *Paradoxides* is confined to the Lower Cambrian, which is sometimes known in consequence as the *Paradoxidian*. The genus *Olenus* marks out in a similar way the rocks of the Upper Cambrian, hence its alternative title of the *Olenidian*. Both Lower and Upper Cambrian rocks are met with in conformable association in Merionethshire and at St David's; elsewhere the two divisions usually occur alone. To the Lower Cambrian are assigned the barren rocks of the Longmynd, Torridon, and Wicklow. The isolated Upper Cambrian is usually formed of a basal quartzite and an overlying series of fossiliferous shales; and in this general sequence is met with in the Wrekin, Caer-Caradoc, the Malvern Hills, and Nuneaton. In North-west Scotland, the interesting and highly fossiliferous Durness-Eriboll series has been provisionally referred to the same Upper Cambrian period, on the ground of its petrological relationships and the similarity of its fauna to that of the Upper Cambrian rocks of North America.

## CHAPTER XIII.

### THE ORDOVICIAN SYSTEM.

186. THE Ordovician forms the central and most typical of the three constituent systems of the Proterozoic or Lower Palæozoic rocks. Like the Cambrian below and the Silurian above, it is locally composed of repetitions of dingy grey-wackès, flagstones, and shales. But it is strikingly contrasted with those systems in the fact that, in many localities, we find these peculiar strata almost wholly wanting, and in their stead we have enormous masses of contemporaneous igneous rocks, or sheets of coarse conglomerates, pale sandstones, and brightly coloured shales. In the Cambrian and Silurian we find but few evidences of the presence of shore conditions, or of volcanic eruptions; and their monotonous deposits appear to have been mainly derived from the degradation of igneous rocks already consolidated. But in the Ordovician period we find abundant local proofs of the existence of shallow water conditions within the British region, and of the presence of active volcanoes. The Ordovician was indeed the "Age of Fire" of the Proterozoic period. In some areas, as in the Snowdonian region of North Wales and the Lake District of the north of England, we find the local Ordovician rocks largely composed of volcanic lavas, ashes, and tuffs, or of the material derived from their aqueous degradation. Accompanying this remarkable development of volcanic energy, we have proofs of local upheavals and depressions of the sea-floor, resulting in shore conditions, and in the formation of masses of coarse conglomerate, sandstones, and sheets of calcareous rock. We find, as a consequence, three very distinct rock-types within the limits of the Ordovician system: the volcanic rocks themselves; the shallow water conglomerates and calcareous

beds ; and the deeper water greywackès, flagstones, and shales. As these various rock-types are followed from region to region, they shade insensibly the one into the other, or alternate irregularly according to the geographical changes in local conditions. Add to this the fact that the creatures inhabiting the shallow waters were necessarily of very distinct types from those dwelling in the quiet sea-depths, and it becomes easy to understand that the working out of the geology and palæontology of the Ordovician system has been one of more than ordinary difficulty, and is still far from being satisfactorily complete.

187. The strata of the system (which varies locally in thickness, from 8000 to 15,000 feet) fall into three main divisions, viz. : (a) *Lower Ordovician* or *Arenig* formation (so called from the Arenig mountains of North Wales, where the igneous rocks belonging to this division are well developed) ; (b) *Middle Ordovician* or *Llandeilo* (from the town of Llandeilo, Caermarthenshire) ; and (c) *Upper Ordovician* or *Caradoc* (from the hill of Caer-Caradoc, central Shropshire, near which its

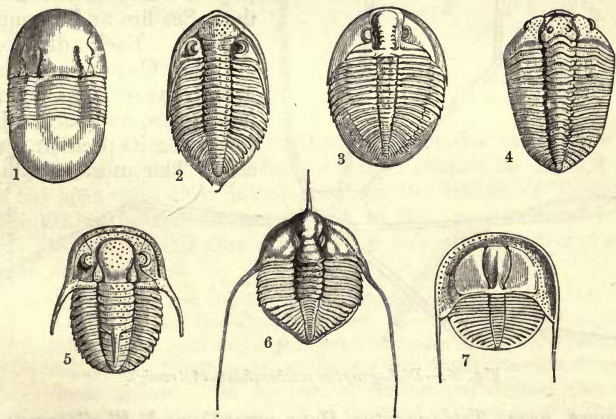


Fig. 65.—Ordovician Trilobites. 1, *Ilænus perovalis* (Llandeilo); 2, *Phacops caudatus* (Caradoc to Ludlow); 3, *Ogygia Buchii* (Llandeilo); 4, *Calymene Blumenbachii* (Caradoc to Ludlow); 5, *Cyphaspis megalops* (Caradoc); 6, *Ampyx nudus* (Llandeilo); 7, *Trinucleus Murchisonii* (Arenig).

fossiliferous beds are well exposed. The fauna of the system, like that of the Cambrian, includes examples of all the invertebrate sub-kingdoms, but usually of totally distinct genera

and species. The great group of the Trilobites, the predominant fossils of the Cambrian system, here sink into a second place. They are, however, still present in great abundance.

The most characteristic forms of the Arenig are *Æglina* (a genus furnished with eyes of remarkable size), *Agnostus*, and *Ogygia*. In the Llandeilo, *Asaphus* and *Ampyx* (a blind form) are also present. In the Caradoc, the prevalent genera are *Trinucleus* and *Calymene*. But by far the most abundant and characteristic creatures of Ordovician time were the *Graptolites* — compound zoophytes allied to the modern Sea-firs and Plumularians. Each division of the Ordovician has usually its own characteristic forms, and each sub-formation its peculiar species. The most striking

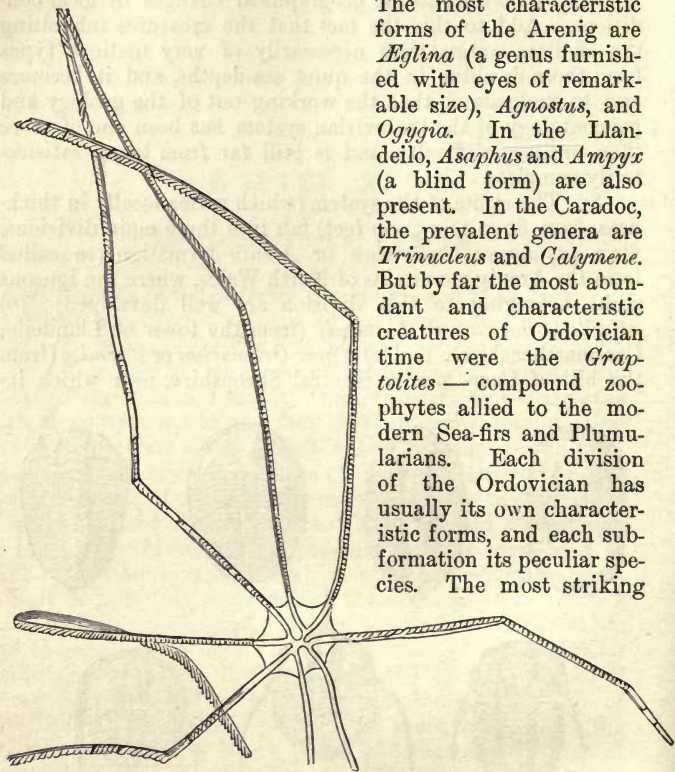


Fig. 66.—*Dichograptus octobrachiatus* (Arenig).

genera are: *Tetragraptus* (four-armed) and *Phyllograptus* (leaf-like) of the Arenig; *Dicranograptus* (two-headed) and *Cænograptus* of the Llandeilo; and *Diplograptus* (double Graptolite), most common in the Caradoc formation. *Brachiopods* are abundant in the Ordovician limestones and sandstones, especially the genera *Orthis* (straight) and *Strophomena* (twisted). The beautiful form *Maclurea* is one of the most characteristic of the Ordovician Gasteropods, and

abundant examples also occur of Cephalopods, Lamelli-  
brachs, and Echinoderms.

188. The largest area of Ordovician rocks occurs in the cen-



Fig. 67.—*Phyllograptus typus* (Arenig).

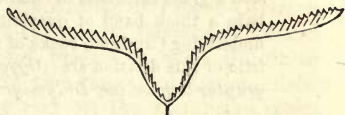


Fig. 68.—*Didymograptus V-fractus*  
(Skiddaw state).

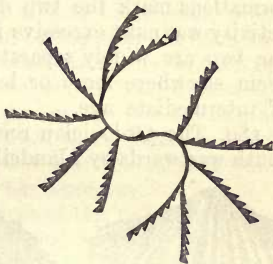


Fig. 69.—*Cænograptus gracilis*  
(Llandeilo).

tral parts of North Wales, which may be regarded as the typical region of the system, and from which it obtains its name, but it has been most fully investigated in the district of Western Shropshire, in the eastern section of the ancient country of the Ordovices. In this district the following sequence has been made out:—

- C. UPPER OR CARADOC division, well developed on the eastern side of the Longmynd and Caer-Caradoc range, where it consists of a great thickness of grits and calcareous sandstones and shales, crowded mainly with Brachiopoda—*Orthes Actoniae*, *Orthis alternata*, *Strophomena grandis*. On the west of the Longmynd these Caradoc strata are in part represented by the local *Chirbury* greywackè formation, which contains a few of the Caradoc fossils in association with *Dicranograptus ramosus* and *Diplograptus foliaceus*, and includes a thick formation of contemporaneous igneous rocks. Below the Chirbury rocks we find the
- B. MIDDLE OR LLANDEILO division, represented by the local *Meadowntown* formation, made up of dark calcareous flagstones and black shales, the former containing *Ogygia Buchii* and *Asaphus tyrannus*, and the latter the Graptolites *Cænograptus gracilis* in their higher zones,

and *Didymograptus Murchisonii* in the lower. This is underlain by the

- A. LOWER OR ARENIG division, represented by the local *Shelve* formation, composed of dark flagstones and shales, having in its highest division a great thickness of contemporaneous volcanic rocks, and at its base a thick band of quartzite (*Stiper Stones*) dividing it from the underlying Cambrian rocks of the Longmynd. The fossils characteristic of this division are—*Ogygia Selwynii*, *Æglina binodosa*, *Tetragraptus bryonoides*, *Didymograptus patulus*, and *Phyllograptus*.

In this district of Western Shropshire we find two thick formations of igneous rock—one at the summit of the Lower Division, the other near the base of the Upper. These two formations mark the two distinct horizons in which volcanic activity was most excessive in Ordovician times. But though the two are widely separated in this district, we often find them elsewhere more or less connected by igneous outbursts of intermediate age.

189. The Ordovician rocks of Shropshire can be followed south-westwards by Llandeilo, Caermarthen, to the sea at Mil-

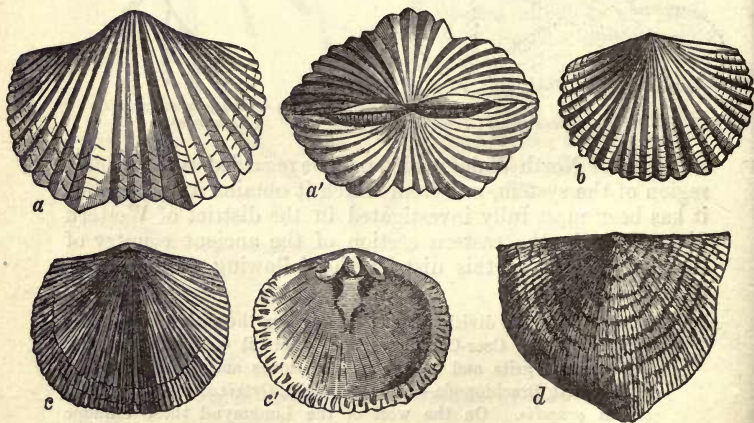


Fig. 70.—Lower Silurian Brachiopods. *a* and *a'*, *Orthis biforata*, Llandeilo-Caradoc, Britain and America; *b*, *Orthis flabellulum*, Caradoc, Britain; *c*, *Orthis subquadrata*, Cincinnati Group, America; *c'*, Interior of the dorsal valve of the same; *d*, *Strophomena deltoidea*, Llandeilo-Caradoc, Britain and America. (Nicholson.)

ford Haven, and are met with again along the same line in the south of Ireland, in the counties of Waterford and Wexford. They are often obscured by later formations; but the three component divisions are locally recognisable, with their char-

acteristic fossils; the Arenig volcanic rocks being also well shown in South Wales, and a higher series in South Ireland. The main mass of the Ordovician rocks occurs, however, in North Wales, of which it occupies almost the entire central area. The lavas and ashes of the Arenig or Lower Division sweep in a vast semicircle from the sea at Barmouth, inland round the towns of Dolgelly and Festiniog, back almost to the sea near Tremadoc, forming the ranges of Cader Idris, the Arans, and Arenigs. They rest on the Cambrian rocks beneath, and dip eastward below an enormous thickness of black shales and greywackes—which constitute the middle and upper divisions of the local Ordovician. These are well developed in the Berwyn Hills and around Lake *Bala*, where they have long been known as forming together the *Bala* formation of Sedgwick. In this formation occurs one of the best marked of the Ordovician limestones (the *Bala Limestone*), below which we again find the higher of the two Ordovician volcanic series. As we pass northward these higher volcanic rocks thicken out rapidly, and constitute the mighty piles of Snowdon, Moel Saibod, and Penmaenmawr.

190. But it is in the mountain area of the Lake District of the north of England where the volcanic rocks of the Ordovician attain their grandest development. The whole of the central area of the Lake region between Keswick and Ambleside is composed of Ordovician volcanic rocks, forming the mountain masses of Helvellyn, &c., and giving rise to the picturesque scenery of the districts of Borrowdale, Conistone, and Ambleside. In this region volcanic action was continuous from Upper Arenig to Middle Caradoc times, and we appear to have no sedimentary representative whatever of the intermediate Llandeilo division in the Lake District. Under the great *Borrowdale Volcanic Series* we find the *Skiddaw Slates*, with the Trilobites and Graptolites of the Arenig rocks of Ordovicia; above the Volcanic series we find a thin limestone (the *Conistone Limestone*), crowded with the characteristic Caradoc fossils.

191. Passing onwards into South Scotland, we find a fairly complete development of the Ordovician rocks in the picturesque district of Carrick in South-west Ayrshire, where a few thin bands of dark shales containing the *Tetragraptus* and *Phyllograptus* of the Arenig are associated with the lower volcanic and igneous series (*Ballantrae Series*); which is followed in turn by massive conglomerates and limestones (*Stinchar Group*), mainly of Llandeilo age; above which the

representatives of the Caradoc rocks occur (*Ardmillan Series*), often crowded with their characteristic fossils. Corresponding Caradoc rocks occur in Central Ulster (Pomeroy) along the same line of direction. All along this northern line the shallow-water facies of the fauna and the local unconformities suggest the existence of land in the north-west direction in Ordovician times—a view which is strengthened also by the extraordinary thickness of the Ordovician sediments in this direction. Midway, however, between the shallow-water deposits of the Lake District to the south and those of the Girvan area to the north, we find evidences of deeper water conditions in the Ordovician, and the strata and fossils put on an entirely new facies. Along a line drawn from St Abb's Head to the south-westward, through the central parts of the southern uplands of Scotland, and thence across Ireland to the Atlantic Ocean, we find small patches of the Llandeilo and Caradoc rocks appearing along eroded anticlines of the newer formations. These Ordovician rocks, which constitute the lower and middle divisions of the well-known Moffat shales, are only a few hundreds of feet in total thickness, but are crowded with Graptolites, which enable us to compare them with the Welsh and Scandinavian deposits of the same age, and show that they were deposited at corresponding times. The extreme thinness of these *Llandeilo* (Glenkiln) and *Caradoc* (Hartfell) shales is due to their great distance from shore at the time of their deposition—a distance, however, not beyond the reach of volcanic material, the dates of the great Ordovician eruptions being marked even here by interbedded bands of felspathic dust.

When we pass to the continent of Europe, we find the Ordovician rocks strikingly contrasted with those of Britain, both as regards thickness and lithological character. They are best developed in Scandinavia and Esthonia. In the latter region they consist entirely of limestones only a few hundreds of feet in total thickness. In Scandinavia they consist in part of limestones, with Brachiopods, and in part of black shales, with Graptolites; and in spite of their insignificant thickness, the same divisions, zone for zone, can be recognised as in Britain. In Belgium a diminutive representative of the Ordovician occurs,—the lower divisions with Graptolites, the upper with Brachiopods. In Brittany the chief member of the Ordovician is a mass of dark slates (Angers slates), with Trilobites. Finally, the Ordovician rocks are well exhibited in Bohemia, where the majority are grits

and shales somewhat resembling those of Wales. In all these European areas the Arenig division is conspicuous, with its characteristic *Dichograptidæ* or *Asaphidæ*; and the Bala, with its abundant *Trinuclei* or *Diplograptidæ*. In North America the lower Ordovician occurs in the valley of St Lawrence, the locality of Point Levis being famous for its Arenig Graptolites. The Llandeilo is mainly represented by a thick limestone, the Trenton Limestone (with *Asaphus*), which ranges from Albany to St Louis and Philadelphia, and a set of *Cæno-graptus* shales (Marsouin shales) which occur at scattered localities from New Brunswick to New Caledonia. The Caradoc rocks are represented by the Utica and Lorraine shales, with *Diplograptus* and *Trinucleus*. Except along the mountain-ranges, the Ordovician beds dip at a gentle angle inland towards the centre of the great Mississippi basin.

192. Scenically, the Ordovician rocks are among the most remarkable in the British Islands. The districts they occupy embrace the grandest and most picturesque areas outside the limits of the metamorphic region of the Scottish Highlands. The mountainous character and picturesque beauty of these districts is due solely to the peculiar characteristics of the Ordovician rocks themselves, and to the frequent alternation of thick masses of hard volcanic rocks with soft, easily eroded tuffs and shales. All the great mountain masses of southern Britain, Snowdon, Cader Idris, Helvellyn, Skawfell, Skiddaw, &c., are composed of Ordovician rocks, or of igneous intrusions in rocks of Ordovician date. The *economic* products of the Ordovician are, however, of no great moment. The Arenig and Llandeilo rocks of Salop, Merioneth, and the Scottish Lead-hills, have long been mined for lead and silver. Plumbago is obtained from veins in the volcanic rocks of Borrowdale, and roofing-slates from the same formation. The physical characters which give the system its remarkable scenic importance also deprive it of almost all agricultural value, its rugged, rock-ribbed areas being simply valuable as stretches of upland pasture.

#### RECAPITULATION.

193. Of the three component systems of the Proterozoic rocks, the Ordovician is by far the most varied as regards the physical characters of its strata, and the striking features of the scenery to which they give rise. The most picturesque Ordovician regions of Southern Britain are—North Wales, in-

cluding the ranges of Snowdon, Cader Idris, Arenig, the Berwyn Hills, the picturesque neighbourhood of Caer-Caradoc in Shropshire, the beautiful Lake District of the N. of England, and the rugged region of Carrick in South Scotland. This scenic distinction is due to the fact that the Ordovician age was a time of remarkable volcanic energy, and the areas named are those in which the chief masses of lava, ashes, and tuffs were laid down. Its sedimentary rocks offer us two distinct types both as regards rocks and fossils—shore deposits of sandstones and calcareous rocks, with *Brachiopoda* and *Trilobites*; and deeper water deposits, greywackès and shales, usually containing *Graptolites* alone. The Ordovician age was distinctly the age of Graptolites, each formation and sub-formation of the system having its own peculiar genera and species. The system is divisible into three grand formations—Lower, or Arenig; Middle, or Llandeilo; and Upper, or Caradoc. The genera *Tetragraptus* and *Phyllograptus* mark the first of these; the genera *Dicranograptus* and *Dicellograptus* occur mainly in the second; and the genera *Leptograptus* and *Diplograptus* in the third. The great volcanic and greywackè types of Ordovician rocks are almost exclusively confined to the British Isles; the Ordovician rocks of Europe and America are almost exclusively sandstones, grits, or shales. Scenically the Ordovician is perhaps the most remarkable of all the British systems. Economically it is of insignificant importance: the hardness and toughness of its rocks giving origin to a bare rugged country, whose meagre coating of soil renders it valueless for the purposes of agriculture.

## CHAPTER XIV.

## THE SILURIAN SYSTEM.

194. THE strata of the Silurian system, over the greater part of their wide geographical range in Britain, present the same general lithological characteristics as those of the underlying Cambrian and Ordovician systems, but they are almost wholly destitute of contemporaneous igneous rocks. They usually occupy the outer flanks of the mountain-ranges formed of the rocks of the older systems, and have in most cases been folded and cleaved with them ; but in some districts they lie at a gentle angle, where their study is comparatively easy and simple. They cover large areas in Wales, Ireland, the N. of England, and the S. of Scotland. In all these districts they present the same general lithological facies, consisting of great thicknesses of greywackè, grits, flagstones, and shales, destitute of limestones, and containing but few fossils excepting Graptolites and Cephalopods ; while their basement beds rest conformably upon the highest strata of the Ordovician. The rocks of the system, however, are met with also in great force along the borders of Wales and the W. of England, ranging in a continuous line from Coalbrookdale, through Shropshire, Hereford, Radnor, and Brecknock to the town of Caermarthen. In this region (the land of the ancient Silures) the Silurian strata put on a wholly distinct facies. The entire system consists of a thick central mass of greyish-green shale and mudstone (locally known as *rotch*) broken up by several thick sheets of concretionary limestone, underlain by a basement series of grits and conglomerate, and capped by a terminal series of calcareous sandstones and flags. Below, its basal strata rest unconformably upon the edges of all the more ancient formations ; above, its highest zones pass conformably

into the lowest strata of the overlying Old Red Sandstone. In the north-eastern portion of this range the rocks of the Silurian system are admirably exposed, and it was in this area (Shropshire and N. Hereford) where Sir Roderick Murchison first worked out and named its component formations. In this typical area the Silurian rocks form a series of picturesque terraces, rising one above the other, the outer edge of each terrace being limited by a steep scarp formed by the eroded outcrop of one of the concretionary limestones, while its upper plateau-like surface is worn out of the strata of one of the intervening shaly formations.

195. The fossils of the Silurian rocks of this typical area present us with examples of all the great groups represented

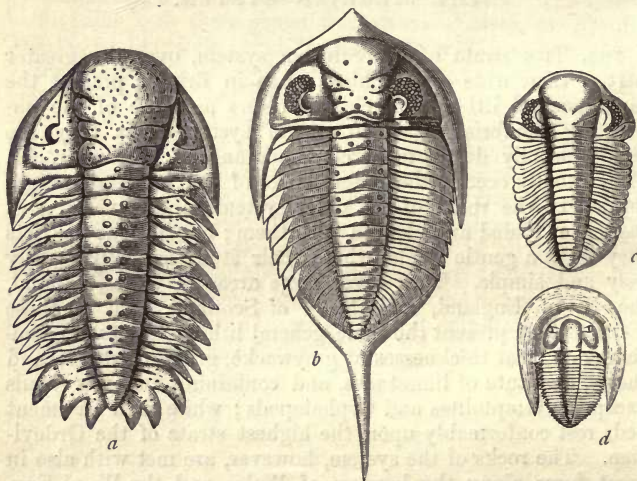


Fig. 71.—Silurian Trilobites. *a*, *Cheirurus bimucronatus*, Wenlock; *b*, *Phacops longicaudatus*, Wenlock; *c*, *Phacops Downingia*, Wenlock and Ludlow; *d*, *Harpes ungula*, Upper Silurian, Bohemia (Nicholson).

in the earlier systems, and, in addition, with the first examples of *Land-plants*, *Vertebrata*, and of the higher *Crustacea*. The traces of Plants (*Pachytheca*, &c.) are confined to the very uppermost beds of the system. The Silurian *Vertebrata* all belong to the great class of the *Fishes*, which make their first appearance in the middle beds of the system, and by the time we reach its summit, appear to have increased largely in abundance and variety. Remains of fishes are remarkably

abundant in a thin bed (*Bone-bed*) at the summit of the system as here exposed. They belong to the orders of the *Ganoids* (*Pteraspis*, &c.), and *Placoids* (*Onchus*, &c.),

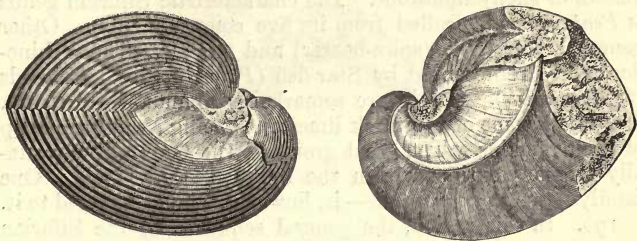


Fig. 72.—*Pentamerus Knightii*, Wenlock and Ludlow. The right-hand figure shows the internal partitions of the shell.

which, with a few rare exceptions, are now extinct. The highest Crustacea (*Pterygotus*, *Slimonia*) of the Silurian also occur mainly in its highest beds. They belong to the extinct order of the Eurypterida, an order somewhat

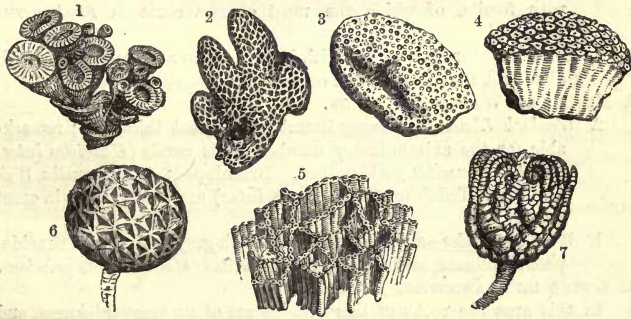


Fig. 73.—Corals: 1, *Cyathophyllum truncatum* (Wenlock); 2, *Favosites cristus* (Llandovery to Ludlow); 4, *Favosites Gothlandica* (Caradoc to Ludlow); 3, *Heliolites tubulatus* (Caradoc to Wenlock); 5, *Halysites catenularius* (Llandeilo to Wenlock). Echinodermata: 6, *Echinosphærites Balticus* (Bala); 7, *Cyathophyllum tuberculatus* (Wenlock).

allied to that of the modern King-crabs. The Trilobites are mainly of genera already occurring in the preceding system (*Phacops*, *Calymene*, and *Homolonotus*).

Mollusca are abundant throughout the system—Cephalopods (*Phragmoceras*, *Orthoceras*, &c.), Lamellibranchs (*Car-*

*diola*), and Gasteropods (*Euomphalus*, *Holopella*). But the most prevalent and characteristic fossils are Brachiopoda, which are sometimes so abundant as to constitute thick masses of shelly limestone. The characteristic Silurian genus is *Pentamerus* (so called from its five compartments). Other genera are *Spirifer* (spire-bearer) and *Atrypa*. The Echinoderms are represented by Star-fish (*Palæaster*) and Crinoids (*Cyathocrinus*). Corals are remarkably abundant (*Favosites*, *Halysites*), some of the thick limestones being almost made up of their remains. The great group of the Graptolites gradually becomes extinct within the limits of the system. One family—the *Monograptidæ*—is, however, wholly confined to it.

196. In this region, the general sequence of the Silurian formations, as developed by Murchison, is as follows:—

C. UPPER OR LUDLOW DIVISION.

3. *Upper Ludlow Rock*, including (c) the *Downton sandstone* and *Passage beds*, (b) the *Bone-bed*, (a) the *Upper Ludlow shales*; composed of red sandstones and calcareous grey shales, with remains of Fishes (*Pteraspis*, *Cephalaspis Murchisoni*), Crustaceans (*Pterygotus*, *Ceratiocaris*), and Plants (*Pachytheca*, *Chondrites*, &c.)
2. *Aymestry or Ludlow Limestone*—concretionary limestone crowded with fossils, of which the most characteristic is *Pentamerus Knightii*.
1. *Lower Ludlow Shales*—greenish-brown shales and mudstones, with abundant Brachiopoda and occasional Star-fish (*Palæaster*).

B. MIDDLE OR WENLOCK DIVISION.

2. *Wenlock Limestone*—flaggy limestone of great thickness; remarkable for the extraordinary number of its corals (*Heliolites interstincta*, *Favosites gothlandica*). Brachiopoda (*Rhynchonella Wilsonii*) and Trilobites (*Phacops caudatus*) are also present in great variety.
1. *Wenlock Shales*—a thick mass of greenish-grey shales, with Brachiopoda, Mollusca, and occasional Graptolites (*Monograptus priodon*).

A. LOWER OR LLANDOVERY DIVISION.

In this area the rocks of this division are of no great thickness, and vary much in local character. The central zone is a hard calcareous rock (*Pentamerus limestone*), characterised by its crowds of the peculiar Brachiopod, *Pentamerus oblongus*. This is surmounted by a thin series of *Purple shales*, and underlain by an irregular sheet of coarse grit and conglomerate (*Mayhill sandstone*), which rests unconformably upon all the rocks below.

197. In this Salopian area, owing in part to the basal unconformity, the complete Silurian series is not present. As we pass to the south-west, a still lower division of the Llandovery makes its appearance, and fills up wholly or in

part the hiatus between the Ordovician and Silurian. This is known as the *Lower Llandovery*, from the name of the town where both sub-formations are seen in sequence.

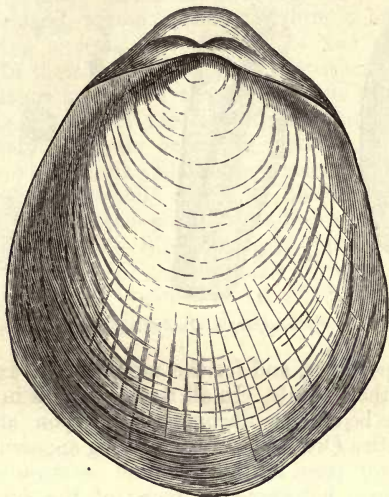


Fig. 74.—Large specimen of *Pentamerus oblongus*.

Lastly, as the Silurian rocks are followed to the southward towards the Malvern Hills, a limestone (*Woolhope limestone*) makes its appearance at the base of the Wenlock shales. Perhaps the most remarkable formation in the Shropshire sequence is that of the Upper Ludlow, which shows a perfectly gradual lithological transition from the Silurian into the Old Red Sandstone. In the middle of the formation occurs a peculiar brownish layer, only a few inches in thickness (*the Bone-bed*), which has been traced at intervals over an area of nearly a thousand square miles, and which is almost wholly made up of fragments of fishes and crustaceans.

198. The Salopian sequence, and the lithological and palæontological peculiarities of its formations, are retained, broadly speaking, unmodified wherever the Silurian rocks are exposed to the south and east of the typical region. Such Silurian rocks are well developed at Woolhope (Herefordshire), in the Malvern Hills, and at Tortworth in Gloucestershire. The entire Silurian sequence occurs also in South Stafford-

shire, where the rocks of the system emerge from below the Coal-measures; and the local Wenlock (Dudley) and Woolhope (Barr) limestones have long been famous for their great

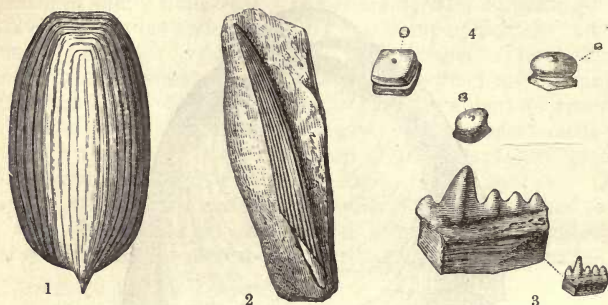


Fig. 75.—1, Head-plate of *Pteraspis*; 2, *Onchus*; 3, *Plectrodus*; 4, Placoid scales.

economic importance, and for the number and excellent preservation of their fossils. In all these areas, as in Shropshire, the Silurian beds rest unconformably upon all the older rocks, the entire Ordovician system being apparently absent.

199. As we pass northwards and westwards from the Shropshire area, however, the rocks of the system rapidly change in all their characters, lithological and palæontological, as well as in their stratigraphical relationships. They sweep in a broad zone from Cardigan through Central Wales and the Berwyn Hills to the Irish Sea near Denbigh. In this region the limestones have wholly disappeared, and with them the varied array of fossils. The whole system has degenerated into an unbroken mass of shales, flagstones, grits, and greywackes, in which almost the only fossils are Graptolites and Orthoceratites; but the main members of the system can, however, still be recognised by their special palæontological characters. The Llandovery is seen to repose as a rule conformably upon the Ordovician, thinning rapidly as it is traced northward, and becoming mainly transformed into a sheet of dark graptolitic shale. The overlying thin band of Purple Shale of Shropshire thickens westwards into a brightly-coloured mass more than a thousand feet in thickness (*Tarannon Shale*), and the Wenlock beds become gradually transformed into an enormous mass of grits (*the Denbigh Grits*). Still retaining the same general characters, the Silurian rocks occur in Westmoreland, with the Llandovery black shales

(*Skelgill Shales*) near the base. Entering the south of Scotland, they sweep in a continuous band across the country from sea to sea, forming most of the region known as the Southern Uplands; and next, crossing the North Channel, pass into Ireland, across which they form a broad zone extending, with a few interruptions, to the shores of the Atlantic. In their range through the Southern Uplands and Central Ireland they retain the monotonous greywackè character of the Silurian of the Lake District and North Wales, even the shaly Tarannon becoming gritty in South Scotland (*Gala Group*); while the Llandovery black shale zone is invariably present (*Birkhill Shales* of Moffat and of Coalpit Bay, Ireland). On the northern and western sides of this greywackè region the Silurian again puts on the varied features of the rocks of the Salopian region. In the Pentland Hills occur local Wenlock and Ludlow rocks, with fossils like those of Shropshire. At Lesmahagow, in Lanark, we

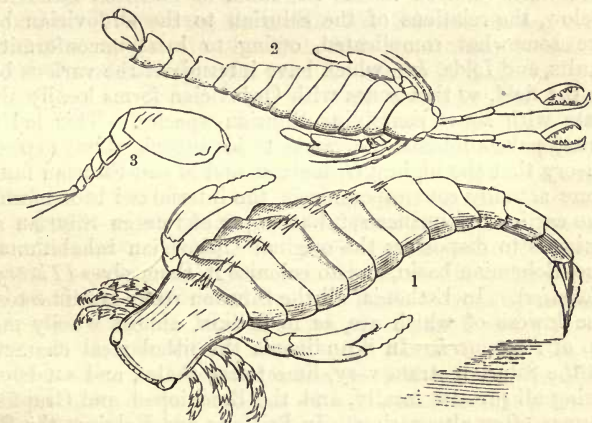


Fig. 76.—1, Dorsal aspect of *Slimonia acuminata*; 2, *Pterygotus bilobus*; 3, *Ceratiocaris* (bivalved Entomostracan). From the highest Silurian or Passage Beds of Lanarkshire.

again find Passage beds with abundant large Crustacea (*Pterygotus*, *Slimonia*, &c.) At Girvan, in Ayrshire, the Llandovery grits and limestones, crowded with *Pentamerus*, like those of Salop, alternate with Llandovery *Monograptus* or *Rastrites* shales containing the fossils of Birkhill.

200. The repeated alternation of limestone and shale in

the Salopian region gives a peculiar character to the scenery of that region, the limestones forming steep scarps, like that of the Wenlock Edge, stretching onwards for many miles, and clothed with thick plantations of oak and fir. Wherever the Salopian rock-type is retained, the same boldly picturesque character of the scenery is developed. In the greywackè districts the scenery of the Silurian resembles that of the underlying system, and has no marked character of its own. Economically the limestones of the Silurian are of first-rate importance. In the South Staffordshire coalfield the Silurian limestones have been worked for centuries (at Dudley and Barr) as a flux for the local ironstones.

201. On the continent of Europe the Silurian rocks are well developed in the central region of Bohemia, where they consist of a great thickness of limestone resting upon a representative of the British Llandovery Graptolite zone below, and passing up conformably above into red rocks, which are sometimes referred to the Devonian or Old Red Sandstone. Below, the relations of the Silurian to the Ordovician beds are somewhat complicated, owing to local unconformities, faults, and folds, &c., which have intermixed the various beds in the field, so that zones with Ordovician forms locally alternate with zones containing Silurian species. This led the great palæontologist Barrande to his ingenious but exploded theory that the highest Ordovician and lowest Silurian faunas were actually contemporaneous, the intermixed beds marking the earlier and unsuccessful attempts of foreign Silurian sea-animals to dispossess the original Ordovician inhabitants of the Bohemian basin, and to colonise it themselves (*Theory of Colonies*). In Esthonia, all the Silurian rocks are limestones, the lowest of which are, as in Britain, almost wholly made up of *Pentameri*. In Scandinavia the lithological characters of the Silurian strata vary, limestones, shales, and sandstones being all present locally, and the Brachiopod and Graptolite faunas often alternating. In Brittany and Belgium the Silurian rocks are mainly graptolitic, as they are also in Spain and Carinthia.

On the opposite side of the Atlantic the Silurian is magnificently developed in the United States and Canada. The Llandovery is represented by sandstones and grits and purple shales (*Oneida and Medina beds*). The Wenlock is seen as a great thickness of limestone (*Niagara Limestone*), as at the Falls of Niagara. The Ludlow is represented locally by a series of barren salt-bearing beds (*Onondago Salt Group*), and

the Passage beds by thick masses of limestone, containing the usual genera of Eurypterids (*Pterygotus*, &c.), and graduating upwards into the Old Red Sandstone.

## RECAPITULATION.

202. In the preceding chapter we have presented an outline of the Silurian System, as at present restricted; or, in other words, of the third and highest of the three component systems of the Lower Palæozoic Rocks. Originally known as the Upper Silurian of Murchison, its rocks were arranged by that geologist into three main divisions—*Llandovery*, *Wenlock*, and *Ludlow*; and though his original work has been amplified and extended by more recent discoveries, these three divisions are sufficient for our present purpose. The rocks of the system present themselves under two very different lithological aspects—the Salopian type of mudstones and limestones, and the Welsh type of flagstones and grits. Everywhere in Britain the Silurian passes conformably upwards into the Old Red Sandstone; below it reposes unconformably upon the Ordovician in England, and conformably in Wales, Scotland, and Ireland. Its fauna is wonderfully rich in Brachiopods (*Pentamerus*, *Spirifer*, *Atrypa*), Corals (*Heliolites*, *Favosites*), and Molluscs (*Orthoceras*, *Euomphalus*, *Phragmoceras*, &c.) The fauna of its highest formations is of the greatest interest, affording the first examples of the giant Crustacea (*Pterygotus*, *Eurypterus*, &c.), of Fishes (*Cephalaspis*, *Auchenaspis*), and of Land Plants. About 5000 feet in thickness in Shropshire, the Silurian thins towards the east, but thickens rapidly to the north-west, until in Denbigh and the Lake District it is 17,000 or 18,000 feet in depth. In North Wales, South Scotland, and North Ireland it is almost wholly composed of greywackè, with the exception of a remarkable black shale group near the base—the Birkhill or Skelgill Shale—characterised by its abundance of Monograptids, the last of the Graptolite families.

203. Scenically, the greywackè development of the Silurian resembles that of the older systems, but the great mudstone and limestone type of Shropshire gives rise to a most picturesque and striking landscape. Economically its southern limestones (Dudley) are of high industrial value, as occurring in a region where the local iron-bearing rocks contain no true limestone bands. On the continent of Europe, the rocks of

the system are almost wholly limestones in Bohemia and Esthonia, mixed limestones and shales in Scandinavia, and mainly shales in Brittany and Belgium. In America they include masses of salt-bearing rocks (Onondago), iron-bearing shales (Clinton), and thick limestones (Niagara); the terminal zones, as in Britain, yielding *Eurypterids*, and passing up conformably into the Old Red Sandstone.

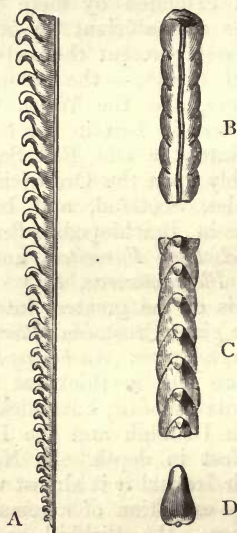


Fig. 77.—*Monograptus priodon*, Bronn (Nicholson).

### SECTION III.—DEUTEROZOIC PERIOD.

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#### CHAPTER XV.

##### THE DEVONIAN OR OLD RED SANDSTONE.

##### OLD RED SANDSTONE OR LACUSTRINE TYPE.

204. THE older geologists, taking the striking and well-studied Carboniferous series as a central system, found in the British Islands one set of reddish sandstones lying *below*, and another set lying *above* it. To the lower set they gave the name of the *Old Red Sandstone*, and to the upper that of the *New Red Sandstone*; and though the progress of science has rendered it necessary to impose certain limitations on these terms, they have still a certain special geological value. The Old Red Sandstone is used at present as the collective name of the thick series of more or less reddish or greyish sandy strata which lie between the Silurian on the one hand and the Carboniferous on the other. These strata are of enormous thickness, and appear to have been laid down in vast fresh-water lakes or in brackish lagoons. They occur in several broad patches to the north and west of a line drawn through the Bristol Channel, across the centre of England, and prolonged over the German Ocean and the European continent in the direction of St Petersburg. The several distinct areas where the Old Red Sandstone beds are exposed have been regarded as ancient lake basins, and to some of these Dr A. Geikie has given distinct names. The chief are those of south Ireland, the area of Hereford and south Wales (*Welsh Lake*), central Scotland (*L. Caledonia*), and a broad area (*L. Orcadie*), including the coast-line of north-east Scot-

land from Banff to John o' Groat's, the Orkney and Shetland Islands, and extending thence to the present west coast of Norway. In nearly all these areas the Old Red rocks are arranged into two divisions—the so-called *Lower Old Red Sandstone* and *Upper Old Red*. These are unconformable with respect to each other; but the Lower Old Red usually shades down conformably into the Silurian below; and the Upper Old Red passes conformably into the Carboniferous above. In north-east Scotland, however, where the Silurian rocks are absent, the Old Red rests at once on the gneisses and schists of the Highlands.

205. The typical Old Red Sandstone, as the name sufficiently indicates, consists of a succession of sandstones, alternating with subordinate layers of sandy shale and beds of concretionary limestones. The sandstones vary in fineness from close-grained fissile flagstone to thick beds of coarse conglomerate, and the shales from sandy laminated clay to soft flaky sandstone. The whole system is more or less coloured by the peroxide of iron—the shales varying from a dull rusty grey to a bright red, and from red to a fawn or cream-coloured yellow. Many of the shales are curiously mottled—green, purple, and yellow—and present an aspect which, once seen in the field, is not soon forgotten. On the whole, shades of reddish colour may be said to pervade the system, unless in some of the northern flaggy bands, which present a dark and semi-bituminous aspect. The flaggy bands of sandstone are locally known as *flagstones* and *tilestones*; the conglomerates, which are merely solidified gravel and shingle, are fancifully termed *pudding-stones*—the pebbles being mingled through the mass like the fruit in a plum-pudding; and the impure limestones are generally known by the name of *cornstones*. The shales are occasionally soft and friable, and in this state are by some termed *marls*; but, from their containing little or no lime, the name is by no means appropriate. In the Upper Old Red Sandstone, *yellow* and red sandstones, conglomerates, and marls prevail; in the Lower, coarse *red* conglomerates, flagstones, red and grey, and thick masses of contemporaneous igneous rocks, chiefly, however, in central Scotland. In this area the Lower Old Red reaches a thickness of 20,000 feet. Of that thickness 6000 feet are volcanic rocks (andesitic and felsitic lavas and tuffs), forming the striking ranges of the Sidlaws, Ochils, Pentlands, Cheviots, &c. In the north-eastern area of Caithness and the Orkneys, the Lower Old Red strata are 16,000

feet in thickness. In their central portions they contain the well-known grey calcareo-bituminous Caithness flagstones of commerce; but traces of igneous action are found only in the Shetland Isles. In Herefordshire the Old Red strata are about 10,000 feet in thickness. They graduate above into the Carboniferous, and below into the Silurian, but they have not yet been found capable of separation into the usual Lower and Upper Divisions.

206. The organic remains of the Old Red Sandstone rocks, though never abundant, are of high and increasing interest, inasmuch as they furnish distinct evidence of terrestrial vegetation, as well as the earliest proofs of abundant vertebrate life on our globe. Among the flagstones and sandstones, and also among some of the more laminated shales, we have impressions of *Fuci*, or sea-weeds (*Chondrites* and *Zosterites*);



Fig. 78.—*Fucoid* (Roxburghshire); 2, *Zosterites* (Forfarshire); 3, *Psilophyton* (Canada).

of marsh-plants apparently allied to the equisetum, the bulrush, and sedge (*Juncites*); and of land-plants akin to the *tree-ferns* (*Adiantites*), *Calamites*, and *Lepidodendron*. On the whole, within the Old Red Sandstone area of Great Britain and Russia (where the system is largely developed), the vegetable remains occur in a fragmentary and carbonised state, as if they had been drifted from a distance to the sea of deposit; but in Canada the plants are much better preserved, and so

abundant as to form, in some instances, thin seams of coal. Among the flaggy shales of the lower groups, as in Caithness, there occur dark bituminous bands of considerable import-



Fig. 79.—*Adiantites Hibernicus* (Upper Old Red of Ireland and Roxburgh).

ance ; but these, it would appear, are the products of animal rather than of vegetable decay, and, as a whole, the system seems by no means fertile in plant-remains.

207. The Fauna of the Old Red Sandstone, on the other hand, is remarkably abundant and peculiar. Taking its strata as more especially investigated in Scotland, England, and Ireland, it may be safely asserted that *fishes* of remarkable structure and organisation constitute the characteristic fossils, so that the Old Red Sandstone is often known as the *Age of Fishes*. The fishes of the period are peculiar, inasmuch as they are covered with bony plates, or with hard enamelled scales ; are frequently furnished with bony spines or external defences ; and are many of them of forms widely different from the fishes of existing seas. Without entering into the anatomy of fishes, we may here explain a few terms frequently made use of by geologists in describing those remains. Fossil, like living, fishes, are either *osseous* or *cartilaginous* ; that is, have either a bony skeleton like the haddock and salmon, or one composed of mere cartilage like the shark and skate. As the scales are often the best-preserved por-

tions of fossil fishes, they were formerly arranged by Agassiz into four great orders, according to the structure of these parts—namely, the ganoid, placoid, ctenoid, and cycloid. 1. The *ganoids* (Gr. *ganos*, splendour) are so called from the shining surface of their enamelled scales. These scales are generally angular, are *regularly* arranged, entirely cover the body, are composed internally of bone, and coated with enamel. Nearly all the species referable to this division are extinct; but the sturgeon and bony-pike of the North American lakes are living examples. 2. The *placoids* (*plax*, a plate) have their skins covered irregularly with plates of enamel, often of considerable dimensions, but sometimes reduced to mere points, like the shagreen on the skin of the shark, or the

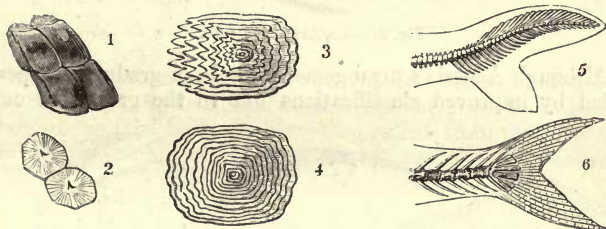


Fig. 80.—1, *Ganoid*; 2, *Placoid*; 3, *Ctenoid*; and 4, *Cycloid Scales*.  
5, *Heterocercal*; 6, *Homocercal Tail*.

prickly tubercles of the ray. This order comprised all the cartilaginous fishes, with the exception of the sturgeon. 3. The *ctenoids* (*kteis*, *ktenos*, a comb) have their scales of a horny or bony substance without enamel, and jagged on the posterior edge like the teeth of a comb. The perch may be taken as a living example of this division. 4. The *cycloids* (*kyklos*, a circle) have smooth, bony, or horny scales, also without enamel, but entire or rounded at their margins. The herring and salmon are living examples of this order, which embraced the majority of existing species. Besides these distinctions it was also usual to recognise fossil fishes as heterocercal and homocercal; that is, according as their tails are apparently unequally or equally lobed. Thus, in *heterocercal* species (*heteros*, different, and *kerkos*, a tail) the tail is chiefly on one side, like that of the shark and sturgeon, the backbone being prolonged into the upper lobe; in *homocercal* species (*homos*, alike) the lobes of the tail appear equal or similar, as in the salmon or herring. In palæontology this distinction, as will

afterwards be seen, is an important one, most of the fishes of the palæozoic periods being heterocercs, the equally-lobed tails being characteristics of more recent and existing species.

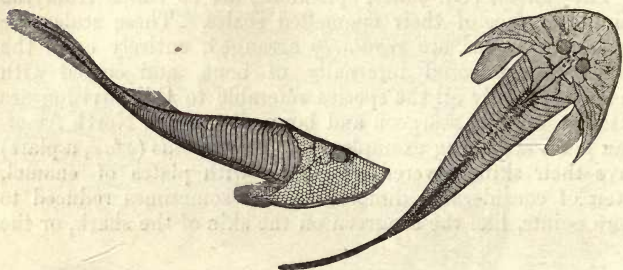


Fig. 81.—*Cephalaspis Lyelli*.

Although Agassiz's arrangement has been gradually superseded by improved classifications due to the growth of our

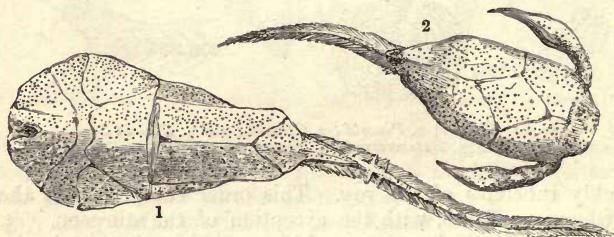


Fig. 82.—1, *Coccosteus cuspidatus* ; 2, *Pterichthys Milleri*.

knowledge, it has not only a historical, but also a high systematic value. Of the four sub-classes into which fishes are

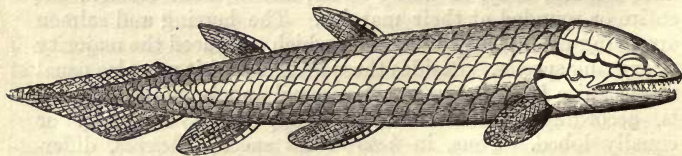


Fig. 83.—*Osteolepis major*, restored outline (Pander).

divided by recent authorities, the chief are the *Teleostei* (modern or perfect-boned fishes) and the *Palæichthyes* (the cartilaginous or ancient fishes). It is to this last sub-class that the

Old Red Sandstone fishes belong. This sub-class is composed of two of the primary orders of Agassiz—viz., the *Ganoidei* and the *Placoidi*—the members of the former being the more abundant. Of the Old Red Sandstone ganoids we may notice two fairly distinct groups. The first group includes the more

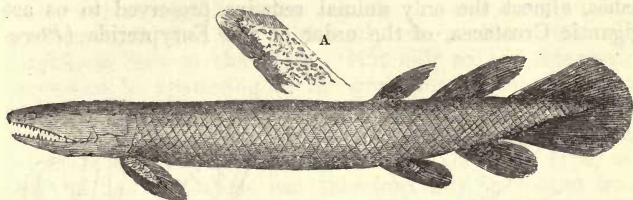


Fig. 84.—*Glyptolemus Kinnairdi*, restored outline. A, Scale of do.

striking Deuterozoic forms—viz., *Cephalaspis*, or buckler-head (Gr. *kephalè*, the head, and *aspis*, a buckler); the *Coccosteus*, or berry-bone (Gr. *kokkos*, a berry), so called from the berry-like tubercles which stud its bony plates; and the *Pterichthys*, or

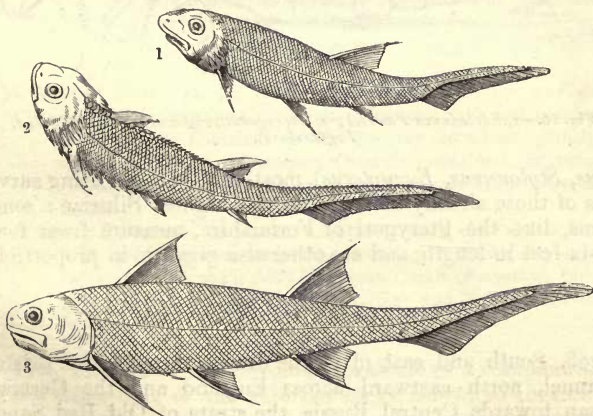


Fig. 85.—1, *Acanthodes Mitchelli*; 2, *Climatius scutiger*; 3, *Diplacanthus gracilis* (Forfarshire).

wing-fish (Gr. *pteryx*, a wing, and *ichthys*, a fish). A second ganoid group, allied to certain curious fishes now living in the Nile, Senegal, &c., includes the *Holoptychius*, or all-wrinkle (*holos*, entire, and *ptychè*, a wrinkle), so termed

from the wrinkled surface of its enamelled plates; *Osteolepis* or bone-scale (*osteon*, a bone, and *lepis*, a scale); and *Diplacanthus* or double-spine, and *Dipterus* or double-fin. The *Placoides* are represented mainly by their teeth and their defensive spines (*ichthyodorulites*—*ichthys*, a fish, *doru*, a spear, and *lithos*, a stone). In addition to the abundant fishes, almost the only animal remains preserved to us are gigantic Crustacea, of the order of the Eurypterida (*Ptery-*

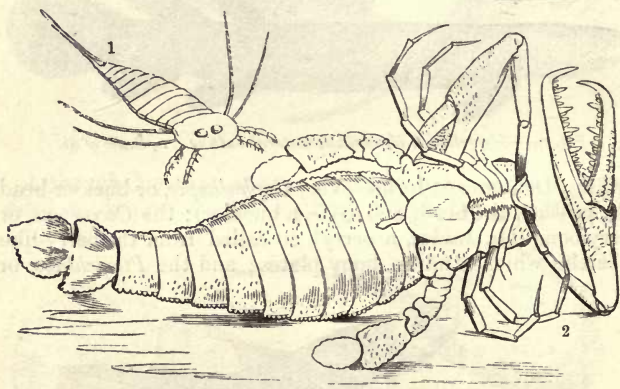


Fig. 86.—1, *Stylonurus Powriei*; 2, *Pterygotus Anglicus* (Lower Old Red, Forfarshire).

*gotus*, *Stylonurus*, *Eurypterus*), most of the genera being survivors of those already met with in the highest Silurian: some forms, like the *Pterygoti* of Forfarshire, measure from four to six feet in length, and are otherwise gigantic in proportion.

#### DEVONIAN OR MARINE TYPE.

208. South and east of a line drawn through the Bristol Channel, north-eastward across England and the German Ocean towards Central Russia, the strata of Old Red Sandstone age put on a totally different aspect, and yield a totally different set of fossils. While the older rocks to the north-west of this line were bent up into vast folds, forming the grand lakes in which the coarse fresh-water deposits of the Old Red Sandstone were laid down, those lying to the south-east of the line simply underwent a gradual depression below

the sea-level, and were covered up by masses of mechanical and organic marine sediment, which are crowded with marine fossils. These marine strata are well developed in Devonshire, where they were first studied by Murchison, Sedgwick, and Lonsdale, and named *Devonian*. Their base is not seen, but they pass up conformably into the lower Carboniferous rocks, and answer clearly as regards age and stratigraphical position with the very differently characterised Old Red Sandstone beds to the north. Not only so, but this marine succession, as answering to the great marine systems above and below, must be regarded as the *type system* for the lower Deuterozoic age. The vast majority of the rocks of this age belong in all parts of the world to this Devonian type, and the Old Red Sandstone can therefore only be looked upon as a local and fresh-water representative of the marine Devonian.

209. In Devonshire the rocks of the system fall into three main divisions, viz. :—

C. UPPER DEVONIAN.—

3. Grey shales and calcareous beds ; with yellow, brown, and red sandstone ; 3000 feet. Plant remains. Species of *Clymenia* (*C. Sedgwickii*, *C. plicata*), *Goniatites* (*S. multilobatus*). Brachiopods (*Spirifera Verneuxi*, and *Trilobites* (*Phacops latifrons*).

B. MIDDLE DEVONIAN, OR ILFRACOMBE GROUP.—Barren grey slates, calcareous slates, and limestone (*Torquay*), grits and conglomerates. Fossils abundant in the Torquay limestone, principally Corals (*Favosites polymorpha*, *Calceola sandalina*), Brachiopoda (*Stringocephalus Burtini*), and Lamellibranchs (*Megalodon cucullatus*).

A. LOWER DEVONIAN, OR LYNTON GROUP.—Slates, somewhat schistose, with red micaceous sandstone, occurring in North Devon ; base not visible. A single fish (*Pteraspis*), Corals (*Favosites*), Brachiopoda (*Atrypa reticularis*, from Silurian), and *Trilobites* (*Phacops lacinatus*).

210. The life of the Devonian rocks shows a complete transition from that of the Silurian rocks below, to that of the Carboniferous rocks above, and so gradual is the change that it has been proposed by some theorists to unite the Upper and Middle Devonian with the Carboniferous ; while others, impressed more by the great unconformity between the Lower and Upper Old Red Sandstone, have proposed to unite the former with the Silurian and the latter with the Carboniferous. There can be no question, however, that both in thickness of

sediment and in length of time, the Devonian or Old Red Sandstone is systematically equivalent to most of the other geological systems, while its transitional character in Devon

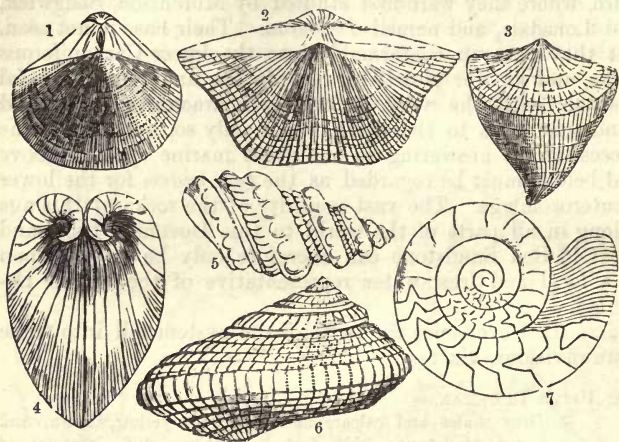


Fig. 87.—Devonian Fossils. Brachiopods: 1, *Stringocephalus Burtini*; 2, *Spirifer disjunctus*. Coral: 3, *Calceola sandalina*. Lamellibranch: 4, *Megalodon cucullatus*. Gastropods: 5, *Murchisonia spinosa*; 6, *Pleurotomaria aspera*. Cephalopod: 7, *Clymenia striata*.

is fully counterbalanced by its striking distinctness in Scotland and the north.

211. The hills of Old Red Sandstone districts present great diversity of scenery: here rising in rounded heights, there sinking in easy undulations; now swelling in sunny slopes, and anon retiring in winding glens or rounded valleys of great beauty and fertility. The Ochils and Sidlaws of Scotland, and the hills of Hereford, Brecknock, and Monmouth in England, belong exclusively to this formation, and may be taken as a type of its physical features; the steep flanks and frequent crags of the Scottish ranges marking the places of the interbedded igneous rocks, the soft outlines of the Herefordshire hills being due to the absence of all local volcanic activity. The Devonian rocks are equally picturesque. The striking cliff scenery of North Devon, and the beautifully varied aspect of the district round Torquay and other parts of South Devon, are wholly due to the peculiar characteristics of the Devonian rocks.

212. Economically, the Old Red rocks are not of prime im-

portance. From the flaggy or laminated beds we obtain such flagstones as those of Arbroath and Caithness, so extensively employed in paving. Greyish building-stone, like that of Dundee and Perth, is obtained from the compacter sandstones of the lower group; and freestone of the finest grain and colour is likewise obtained from the upper group in Roxburgh and in Fifeshire. The porphyrites and greenstones are exceedingly durable, but are seldom used in building, owing to the difficulty of dressing them into form. They make first-rate road materials, however, and for this purpose are largely employed in the districts where they occur. To the traps of the Old Red the lapidary is chiefly indebted for most of the agates, jaspers, carnelians, and chalcedonies, known as "Scotch pebbles"—these gems being usually found in rough-looking nodules among the debris of the disintegrated rocks, or in the softer amygdaloids which are sometimes quarried for the purpose. The Devonian rocks are famous for their altered limestones, or so-called marbles, of which that of Torquay is the best-known example. They also yield, locally, ores of the metals—iron, lead, and copper.

213. Abroad, the rocks of the system are almost wholly those of the marine or Devonian type. They extend almost continuously across Europe in a broad band through north France (the Ardennes), Belgium, and the Rhine provinces of Prussia to the Harz Mountains, showing the same threefold palæontological division as in the south-west of England. The central limestone group is well displayed in the Eifel district, containing abundant corals, among others the curious *Calceola sandalina*. Occasionally the beds of the lower and upper divisions of the system show coarse conglomerates, sandstones, and greywackès, but their fossils are always of a marine type. They are found again covering a large tract of country in Russia, where they lie almost horizontally; and we find, in addition to marine limestones with Devonian fossils, coarse red sandstones and marls with *Holoptychius* and other genera of the Old Red Sandstone fishes. In North America the Devonian rocks attain a great thickness and have a wide extension. The lowest beds contain terrestrial plants (*Psilophyton*); the highest are red sandstones (Catskill group), and yield the Old Red Sandstone genera *Holoptychius*, &c.; but the main masses of the American rocks of the system are of the Devonian type.

## RECAPITULATION.

214. The system we have now reviewed, under the title of the Devonian or Old Red Sandstone, is one of the most remarkable in the geological record. In Britain its strata are of two wholly distinct types. The northern type consists of coarse conglomerates, red sandstones, and marls—presumably laid down in fresh-water lakes or brackish lagoons—and yielding an abundance of *fishes* of a most peculiar type (*Ganoids*),—covered with hard enamelled scales, or with bony plates, or armed with strong spines; and associated with gigantic crustacea (*Eurypterites*), somewhat allied to the modern king-crab. To the northern type the name of Old Red Sandstone is generally applied. Its rocks are separable into an Upper and Lower Division—unconformable with respect to each other, but graduating, the one upwards into the Carboniferous, the other downwards into the Silurian. The southern type of the system is known as the Devonian, from the county where its strata are best displayed. They consist of grey sandstones, shales, and limestones arranged in three main divisions, and characterised by peculiar corals—Cephalopods, Brachiopods, and Trilobites—which constitute collectively a marine fauna which is perfectly intermediate between those of the Silurian and Carboniferous. Abroad, almost everywhere, the Devonian type of the system prevails; and thus the Old Red Sandstone can only be regarded as a local variation of the great Devonian system. The Old Red Sandstone proper appears to have been mainly deposited in great lakes, the boundaries of which can still be dimly recognised, and which have received distinctive names. In central Scotland the lower Old Red Sandstone is remarkable for its masses of interbedded volcanic rocks—of which the Sidlaws, Ochils, Pentlands, and Cheviots are the best examples; and the great masses of granite in the Grampians and the Southern Uplands may perhaps mark the sites of some of the reservoirs of the great volcanoes of this ancient period. The scenery of the districts covered by the rocks of the system varies greatly—from the steep and rugged hill-ranges of the Lower Old Red of central Scotland, built of alternate sheets of igneous and aqueous material, through the slaty and highly picturesque hills of North and South Devon, to the soft-flowing heights of Salop and Hereford. The economic products of the system are few

—the most important being the bituminous flagstones of Caithness, generally employed in Britain for paving purposes, and the beautiful limestone of Torquay, the well-known ornamental “Devonshire marble.”

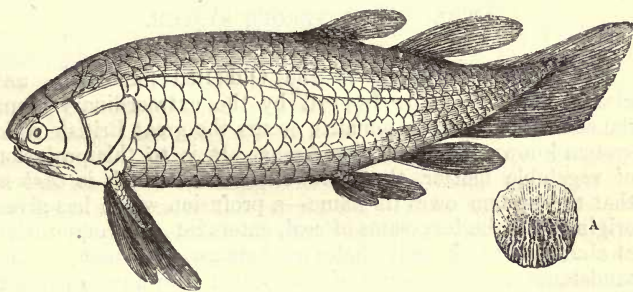


Fig. 88.—*Holoptychius nobilissimus*, restored outline. A, Scale of do.

## CHAPTER XVI.

### THE CARBONIFEROUS SYSTEM.

215. IMMEDIATELY above the Old Red Sandstone, and clearly distinguishable from it by the extraordinary abundance of its vegetable remains, occurs the great British rock-system known as the *Carboniferous*. It is to this profusion of vegetable matter, the main element of which is *carbon*, that the system owes its name—a profusion which has given origin to numberless seams of coal, enters into the composition of abundant black coaly shales, and stamps even many of the sandstones and limestones of the system with a carbonaceous aspect. This system, the rocks of which attain collectively a thickness which has been estimated at above 20,000 feet, is altogether the typical system of the Deuterozoic age—whether we have regard to its thickness, its wide geographical extent, the abundance of its organic remains, or the economic value of its products. Mined in many districts for its coals and ironstones, its sandstones or limestones, the Carboniferous has been longer known and studied than any of the other Palæozoic systems; and our knowledge of the physical conditions and life-aspect of the period in which its strata were deposited is minute and fairly complete.

216. The strata of the Carboniferous are of great variety as regards their lithological composition. They include massive limestones of marine origin, thousands of feet in thickness; sheets of hard sandy gritstone, of equal vertical extent. There are sandstones of every degree of purity, from thick beds composed of white quartz grains, to flaggy strata differing little from sandy shales; shales, from soft laminated clays to dark slaty flags, and from these to beds so bituminous that they are scarcely distinguishable from impure coals; and

limestones, from sparkling saccharoid marbles to calcareous grits and shales. Besides these varieties of sandstones, clays, shales, and limestones, there occur, for the first time notably in the earth crust, seams of *coal* and bands of *ironstone*. These very different rocks were necessarily deposited under very different conditions—the limestones in the clear waters of broad seas; the grits at the mouths of rivers, or along the shore-lines; the coals and ironstones in estuaries, swamps, and land-locked lagoons. We find the limestones predominating in the lower division of the system, marking the time when much of the British area must have been depressed far below the sea-level. The sandy beds *prevail* in the middle division, indicating the main period of slow upheaval. The coals and ironstones occur chiefly in the highest division, when the land had been almost wholly lifted above the sea-level, and become transformed into a region of vast river-deltas and broad swampy plains, clothed with the richest and most luxuriant vegetation. But the times of *local* upheaval were not always the same throughout the whole of the British area, some parts of the sea-floor becoming elevated into land, while others yet remained under the sea-waters. Thus not only do we find a *vertical* variation in the lithological characters of the rocks of the Carboniferous system, but also a *lateral* one; the grits, coals, and ironstones of some localities answering in place and time to the limestones and calcareous sandstones of others.

217. The actual sequence of the Carboniferous rocks varies in every district of Britain; but the following table expresses the order where the beds are thickest and most complete, as along the southern parts and flanks of the Pennine chain:—

#### UPPER CARBONIFEROUS, OR COAL-MEASURES.

3. *Upper Coal-Measures*.—Sandstones and clays, red and grey, with a few coals, and containing usually a remarkable band of limestone (*Spirorbis limestone*), with *Spirorbis carbonarius*.
2. *Middle or Main Coal-Measures*.—Grey sandstones, clays, and shales, with abundant coal-seams. Fossils:—fishes (*Megalichthys*, *Rhizodus*, *Ctenacanthus*), fresh-water molluscs (*Anthracosia*), conifers (*Dadoxylon*), and abundant cryptogamous or flowerless plants (*Sigillaria*, *Lepidodendron*, *Ferns*, and *Equisetacæ*).
1. *Gannister Beds*.—Hard flagstones (locally known as *Gannister*), shales, and a few coals, with occasional marine fossils in some of the beds (*Orthoceras*, *Lingula*).

#### MILLSTONE GRIT.

Coarse gritstones, often of enormous thickness, with local shales.

## LOWER CARBONIFEROUS, OR CARBONIFEROUS LIMESTONE SERIES.

3. *Foredale Beds*.—Flagstones, calcareous, with many local limestones. (Marine fossils—*Aviculopecten*, *Lingula*, *Goniatites*.)
2. *Mountain Limestone*.—Thick limestones in central England and Ireland, 2000 feet in thickness, passing laterally into sandstones and coals. Fossils :—mainly Corals (*Lithostrotion*, *Zaphrentis*), Echinoderms (*Pentremites*), and Mollusca (*Productus*, *Spirifer*, *Nautilus*, *Goniatites*).
1. *Lower Limestone Shales*.—Shales, with marine fossils in centre and south of England, passing down conformably into the upper beds of the Old Red Sandstone, and represented by sandstones, shales, and thin limestones in north England, central Scotland, and south Ireland.

## SOUTHERN TYPE OF THE LOWER CARBONIFEROUS, THE MOUNTAIN OR CARBONIFEROUS LIMESTONE.

218. This remarkable limestone formation is one of the most distinct and unmistakable in the whole crust of the earth. Whether consisting of one thick reef-like mass of limestone, or of many beds with alternating shales and gritty sandstones, its peculiar corals, encrinites, and shells, distinguish it at once from all other series of strata. In fact, it forms in the rocky crust a zone so marked and peculiar, that it becomes a guiding-post not only to the miner in the Carboniferous system, but to the geologist in his researches among other strata. It has received the name of *Mountain Limestone*, because it is very generally found forming, flanking, or crowning the mountain-ranges of the north of England, and most of the hills that intervene between the Old Red and the Coal-measures, where, from its hard and durable texture, it forms bold escarpments, as in the hills of Derbyshire, Yorkshire, Westmoreland, Fife, and many parts of Ireland. It is also termed the *Carboniferous Limestone*, from its occurring in the heart of that system, and constituting one of its most remarkable features. On the southern portions of the Pennine chain, especially in and around the county of Derby, the formation puts on its most typical aspect, consisting mainly of a compact, well-bedded limestone of a light bluish-grey colour, and from 2000 to 4000 feet in thickness. To the northward of the typical localities, it gradually becomes split up by intercalated sandstone and shales, until, when we reach the Scottish border, the whole formation has put on a very different aspect. But even as far northward as Durham and Northumberland, the main mass of lime-

stone (the *Scar Limestone*) is still from 500 to 1000 feet in thickness. Along the line of the Pennine chain, the Carboniferous Limestone graduates upwards into a series of calcareous sandstones, limestones, and shales, known as the *Yoredale Rocks*, which increase in thickness from 2300 feet in north Staffordshire to 4500 feet in some parts of Lancashire. In south Wales the carboniferous limestone again puts on its normal homogeneous character, but dwindles down to a thickness of 500 feet. In central Ireland, however, it again attains almost its original thickness, spreading out in an almost continuous sheet from sea to sea.

219. The fossils of the great Carboniferous Limestone itself, if we except the plants, &c., drifted from shore, are almost wholly marine; and in general the observer feels as little difficulty in accounting for its formation, as he does in

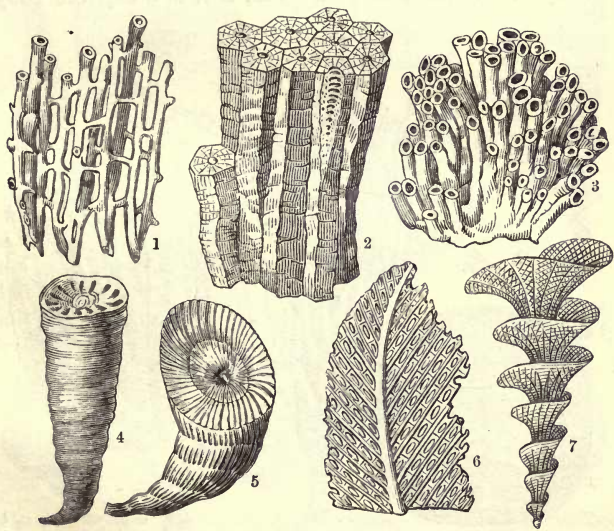


Fig. 89.—Corals: 1, *Syringopora reticulata*; 2, *Lithostrotion basaltiforme*; 3, *Syringopora geniculata*; 4, *Amplexus coralloides*; 5, *Clisiophyllum turbinatum*. Polyzoa: 6, *Ptilopora flustriformis*; 7, *Archimedopora reversa*.

accounting for the origin of existing coral-reefs and shell-beds. We find relics of an exuberant fauna in the sea-waters of the time, including members of all the great groups of the Invertebrata, together with enamel-scaled fishes of huge and sauroid

aspect. Chief, however, are the Zoophytes, mainly Corals, of the exuvæ of which the mighty reef-like masses are mainly composed. We have cup-corals, star-corals, tube-corals, and branching and lamelliferous corals. The most abundant are the *Cyathophyllum* (cup-leaf), *Clisiophyllum* (curl-leaf), *Lithostrotion* (stone-spread), *Syringopora* (pipe-pore), and other forms—all receiving their designations from some peculiarity of form or structure. Next in abundance follow the Echinoderms, of which the most prevalent are the Encrinites (*Crinoidea*, or sea-lilies), whose jointed stems and branches often make up the entire mass of limestone. As Trilobites were specially characteristic of the Silurian period, and bony-plated fishes of the Old Red Sandstone, so may Encrinites be regarded as peculiarly distinctive of the mountain limestone. They occur in endless varieties, but are all constructed on the same plan—viz., that of a cup-like body,

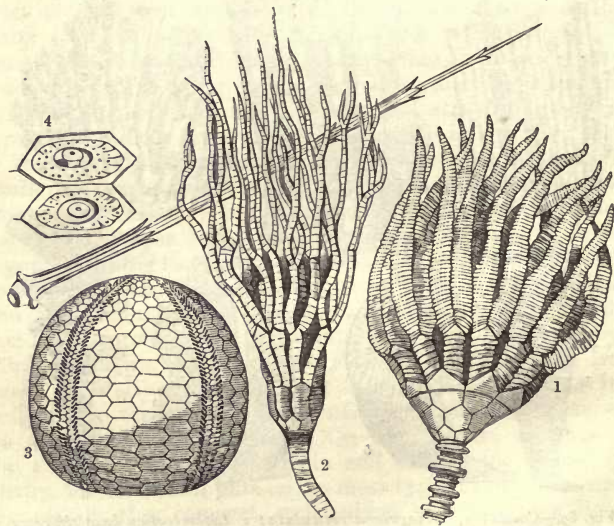


Fig. 90.—Encrinites: 1, *Woodocrinus macrodactylus*; 2, *Cyathocrinus planus*. Echinoidea: 3, *Palæchinus sphaericus*; 4, Plates and Spine of *Archæocidaris Uriei*.

furnished with numerous arms and branches, and attached to the sea-bottom by a jointed and flexible stalk. They derive their names chiefly from the shape of their cup-like bodies, or

from that of the calcareous joints which compose the stalk. Thus we have *Cyathocrinus*, so called from the cup-like shape of its body; *Actinocrinus* (rayed); *Platycrinus* (broad); the *Woodocrinus*, named after its discoverer, Mr Wood of Richmond; and many others. Other Echinoderms are the *Pen-*



Fig. 91.—Molluscoidea—Brachiopods: 1, *Terebratulula hastata*; 2, *Productus giganteus*; 3, *Spirifer cameratus*. Mollusca—Gasteropods: 5, *Bellerophon costatus*; 6, *Loxonema*; 7, *Murchisonia trilineata*; 8, *Pleurotomaria flammigera*; 9, *Euomphalus pentangulatus*. Lamellibranch: 4, *Aviculopecten papyraceus*. Pteropod: 10, *Conularia quadrisulcata*. Cephalopods: 11, *Goniatites striatus*; 12, *Orthoceras laterale*.

*trimites* (so called from the five-rayed nature of their calyx), and a few sea-urchins (Echinoids), some of which differed from the common sea-urchins of our present shore in the

circumstance that their shell was more or less flexible. Sponges appear to have been excessively abundant in some areas, their spicules accumulating to form thick beds of chert, or siliceous rock, as in the Carboniferous Limestone of north Wales and of central Ireland. The first class of the Molluscoida is also well represented—namely, the Polyzoa, to which belong the curious so-called lace-corals (*Fenestella*), screw-corals (*Archimedes*), &c. The Brachiopoda were not so prevalent as in the Proterozoic rocks; but of such as are found, many are of remarkable form and size. Such, for example, are *Productus* (produced), *Terebratula* (pierced, having an orifice at its apex, through which passed a process for attachment to foreign objects), *Spirifera* and *Lingula*, the last named being scarce in the limestones, but abundant in the coaly shales. Of the great sub-kingdom of the Mollusca we find abundant Lamellibranchs (*Avicula*, *Aviculopecten*, *Posidonomya*, *Modiola*); Gasteropods (*Euomphalus*, *Bellerophon*, *Mur-*

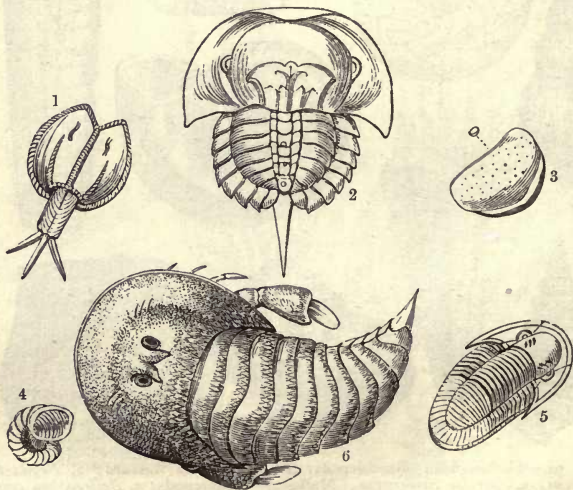


Fig. 92.—Crustacea: 1, *Dithyrocaris testudineus*; 2, *Limuloides* (*Belinurus*) *rotundatus*; 3, *Cypris*, magnified; 4, *Spirorbis carbonarius* (*Annelid*), magnified; 5, *Phillipsia pustulosa* (*Trilobite*); 6, *Eurypterus* (*Idothea*) *Scoulerii*, from *Lithgowshire*.

*chisonia*); and Cephalopoda (*Nautilus*, *Goniatites*, and *Orthoceras*), some of the last named being occasionally five or six feet in length

The annelides, *Serpula* and *Spirorbis*, are found in all the groups; and also the Crustaceans *Cypris*, *Dithyrocaris*, and *Limuloides* or *Prestwichia*. The Trilobites, *Phillipsia* and

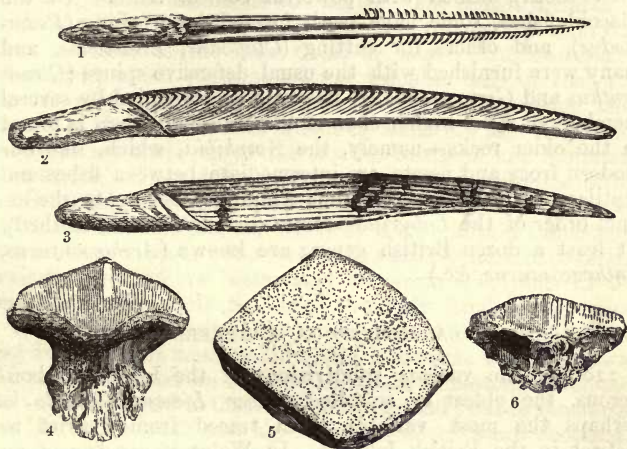


Fig. 93.—Fishes: 1, *Pleuracanthus levissimus*; 2, *Gyracanthus formosus*; 3, *Ctenacanthus arcuatus*; 4, *Petalodus Hastingsii*; 5, *Psammodus porosus*; 6, *Ctenoptychius serratus*.

*Griffithides*, are confined rather to the shales of the Mountain Limestone.

The fishes remind us much of those of the preceding

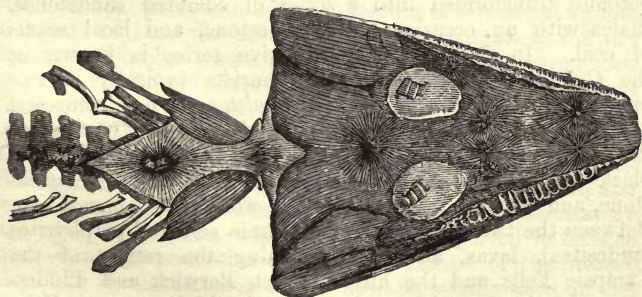


Fig. 94.—*Archæosaurus minor* (Goldfuss).

Old Red Sandstone rocks, and are more prevalent in the shaly and sandy series than in the limestones. They be-

long, like them, mainly to the *Ganoidei* and *Placoidei*. Of the former the second section (fringe-finned) is mainly represented by the fierce *Megalicthys* (big fish) and *Rhizodus* (root-tooth), armed with powerful conical teeth. Of the Placoid fishes, some have teeth formed for crushing (*Psammodus*), and others for cutting (*Cladodus*, *Petalodus*), and many were furnished with the usual defensive spines (*Ctenacanthus* and *Gyracanthus*). They are accompanied by several members of a yet higher class of the *Mammalia* than is found in the older rocks—namely, the *Amphibia*, which, like our modern frogs and newts, are intermediate between fishes and reptiles. All the Carboniferous Amphibia belong to the extinct order of the *Labyrinthodontia* (or labyrinthine-toothed). At least a dozen British genera are known (*Archægosaurus*, *Anthracosaurus*, &c.)

#### LOWER CARBONIFEROUS, NORTHERN TYPE.

220. Of the various subdivisions of the Lower Carboniferous, the oldest or so-called *Lower Limestone Shale* is perhaps the most variable when traced from district to district in the British Islands. In Wales it consists of an insignificant thickness of shales, forming the introductory layers of the overlying Carboniferous Limestone. As we pass northward from central England into Scotland these shales and the lower portion of the Carboniferous Limestone above them undergo a most remarkable lithological change. The limestones gradually disappear, and the group becomes transformed into a series of coloured sandstones, shales with an occasional thin limestone, and local seams of coal. In Scotland this collective series is known as the *Calcareous Sandstones*. It consists typically of two main members—a lower or *Red Sandstone Group*, composed of coloured sandstones and marls, and an upper or *Cementstone Group*, composed of white and yellow sandstones, black shales, thin coals, argillaceous limestone or cementstone, and bituminous shales largely worked for mineral oils. Between the two occurs a thick volcanic series of porphyrites (andesites), lavas, and tuffs, forming the ranges of the Campsie Fells and the hills of East Berwick and Liddesdale. In this Scottish region also the higher parts of the great Carboniferous Limestone of England have undergone an equally remarkable transformation. A few thin limestones are still present (the thickest of which is that of Hurlet in Ayr-

shire, 100 feet), and the formation classed as the Carboniferous Limestone of Scotland shows such limestones at intervals through a thickness of about 2000 feet. But the main masses of its strata are sandstone and shales. The central member of this so-called Limestone series is a coal-bearing formation 600 feet in thickness (the *Edge Coals* or *Lower Coal-Measures* of Scotland), which contains several valuable beds of coal and layers of ironstone. Its coal-beds contain the usual land plants of the English Coal-Measures, while the thin limestones between are made up of the marine fossils of the Mountain Limestone. The thickness of the Lower Carboniferous Series of Scotland, which thus represents both the Limestone Shales of South England and the whole of the Mountain Limestone, varies from 3000 to 7000 feet, and is clearly indicative of the existence of shallow water and estuarine conditions in the northern area, while the more southerly English region remained still submerged below the clear waters of the broad sea in which the massive Mountain Limestone was laid down. In central Ireland we find the Mountain Limestone developed to an extent equal to that of central England; but to the north, as Ulster, its lower beds agree with those of south Scotland; while to the extreme south, in the counties of Cork and Kerry, the Lower Limestone Shales have thickened out to a mass of grey grits, slates, shales, and impure limestones (the *Glen-gariff Grits* and *Carboniferous Slates*) at least 5000 feet in collective thickness. In this complex Lower Carboniferous series, as thus developed in central and south Scotland, and in the north and south extremes of Ireland, the frequent thin seams of coal point to a local exuberance of terrestrial vegetation, and indicate the existence of a genial climate and of dry lands,—of jungles where trees like the araucaria reared their gigantic trunks—of river-banks where tree-ferns waved their feathery fronds—and of estuarine and marine swamps where gigantic reed-like stems, equisetums, and other marsh vegetation, flourished in abundance. When we turn to the shell-limestones, and find them three or four feet in thickness, and entirely composed of mussel-like bivalves, we are instantly reminded of estuaries where these shell-fish lived in beds as do the mussel and other gregarious molluscs of the present day. In the bituminous shales, now so largely used in the distillation of paraffin-oil, we have obvious proofs of vegetable drift and maceration, analogous to that which characterises the majority of existing deltas. Or if we examine the frequent remains of the fishes which are found in the shales and

limestones, we have ample evidence of their predaceous habits, and are forcibly reminded of shallow seas and estuaries, where huge sauroid fishes were the tyrant-scavengers of the period. A few minute land-shells, and the skeletons of some small amphibia of the frog and lizard kinds, indicate the existence of a terrestrial fauna which becomes more abundant and varied in the higher groups of the system.

#### UPPER CARBONIFEROUS OR COAL-MEASURES.

221. This division derives its name from the fact that it furnishes generally in Britain those valuable beds of coal which contribute so materially to our country's prosperity and power. It is separated from the Lower Carboniferous by a series of beds of quartzose sandstones, known as the *Millstone Grit*, which sometimes, as in Scotland, consists merely of a few feet of coarse sandstone (known as *Moor Rock*, 50 to 600 feet), but which, in England, attains a remarkable thickness, ranging from 400 feet in South Wales, to a depth of 5500 feet in northern Lancashire. Immediately above this sandstone series we come upon the Coal-Measures themselves, which vary greatly in character as they are followed from coal-field to coal-field. In South Wales the division attains its greatest thickness, consisting of three members,—a lower series (600 feet) with thirty-four coal-seams, an upper series (3000 feet) with twenty-six coal-seams, and an intermediate sandy series (*Pennant Grit*) with fifteen coal-seams. In Lancashire and Yorkshire it is also separable into three subdivisions, but of a different character from those of South Wales. At the base lies the *Gannister* coal series (200 feet), flags, shales, and a few coals; in the middle, the Coal-Measures proper (3000 to 4000 feet); and above, the so-called Upper Measures, shales, red sandstones, and a few thin coals (2000 feet). Followed into central Scotland, the Upper Carboniferous often dwindles down to a thickness of about 1400 feet, of which the upper 300 feet are composed of certain so-called *Red Measures* (answering to the highest subdivision of the English rocks, and usually resting unconformably upon the beds below), while the remainder constitute the Flat-coals or *Upper Coal-Measures* of Edinburgh, Fife, and Lanark. In Ireland the Coal-Measures are poorly represented, those of Tyrone being about 1500 feet in thickness. They occur also in Leinster and Clare, but are of no great extent, and contain few workable coals.

222. The Upper Carboniferous, or Coal-Measures, consists,

therefore, of alternations of sandstones, shales, clays, ironstones, coals, and impure limestones. Although among these multifarious beds there is no definite order of succession, yet flaggy and calcareous sandstones may be said to prevail at the base of the group, shales and coals in the middle, and sandstones and marly shales in the upper portion—these gradually passing into the succeeding system of the New Red Sandstone. The Coal-Measure *sandstones* occur in great variety, but are in general of a dull-white or brown colour, and thick-bedded. Occasionally they are thin-bedded or flaggy, but in this case they are more or less mingled with carbonaceous, argillaceous, or calcareous matter. But the most notable feature in the composition of the Upper Carboniferous is the frequent recurrence of seams of coal and beds of bituminous shale—all bespeaking an enormous profusion of vegetable growth, and a long-continued epoch in the world's history when conditions of soil, moisture, and climate conjoined to produce a flora since then unparalleled in rapidity of growth and luxuriance. It is this profusion of vegetable growth, now converted or mineralised into *coal*, which distinguishes the Carboniferous from all other systems in Britain—the lakes and estuaries of the period being repeatedly choked with vegetable matter, partly drifted from a distance by river inundations, but chiefly and most extensively accumulated on the bed of its growth after the manner of peat-mosses, jungles, swamps, and forests. The coals themselves present numerous differences, and are known to

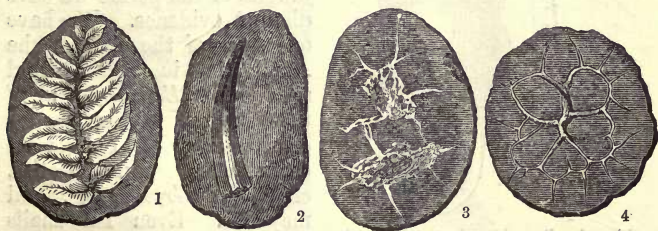


Fig. 95.—Nodules of Ironstone, enclosing—1, *Pinnule of Neuropteris*; 2, *Tooth of Rhizodus*; 3, *Coprolites*; 4, *Septarium proper*.

mineralogists as *anthracite*, a semi-lustrous variety, burning without smoke or flame; *caking-coal*, like that of Newcastle, which cakes or undergoes a kind of fusion during combustion; *splint*, a less bituminous and slaty variety, which burns free and open, without caking; and *cannel*, a compact lustrous

variety, which breaks with a conchoidal or shell-like fracture, and is extensively used in the manufacture of gas. The *shales* are all dark-coloured, and more or less bituminous; the *limestones* often impure and earthy; and the *ironstones* occur in bands or in nodules—either as a clay carbonate of iron (“clay-band”), or in combination with bituminous or coaly matter, as the “blackband” of Scotland. These nodules or *septaria* (Lat. *septum*, a partition) are for the most part aggregated round some organic nucleus, such as a tooth, scale, coprolite, or leaf, and shrink during solidification—the shrinkage cracks filling up with carbonate of lime, and presenting the curious divisions which give them the name of “septaria,” “beetle-stones,” and the like.

223. The organic remains of the Coal-Measures, though exhibiting many features in common with the groups already described, are still, as a whole, peculiarly well defined. As an estuary deposit, many of the beds contain shells (the “mussel-bands” or “mussel-binds” of the miner), fishes, and other aquatic exuviae. A few encrinites appear in certain exceptional beds of limestone, but otherwise marine types are subordinated, and estuary ones prevail.

Of the presence of land animals in the forests and jungles of the period we have distinct evidence. We have examples of the class of the Arachnida in spiders and scorpions (*Eoscorpius*); of that of the Myriapoda (or centipedes); of Insecta in cockroaches and beetles, crickets (*Gryllacris*) and may-flies. Even land-snails (*Pupa*) have been discovered in the Coal-Measures of Nova Scotia. These land-fossils are exceedingly rare. They are nevertheless sufficient to

assure us of the existence, in Carboniferous times, of a land fauna which had reached a very high stage of development. The grand feature, however, of the period, is the

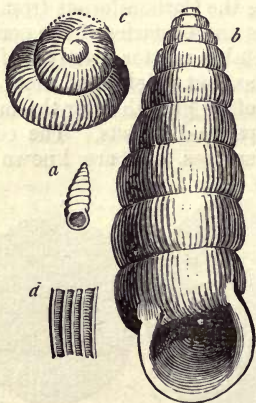


Fig. 96.—*Pupa (Dendropupa) vetusta*, a Carboniferous Land-snail from the Coal-Measures of Nova Scotia. *a*, The shell, of the natural size; *b*, The same, magnified; *c*, Apex of the shell, enlarged; *d*, Portion of the surface, enlarged. (After Dawson.)

abundant and gigantic *flora*, comprising hundreds of forms, most of which have now only distant representatives in

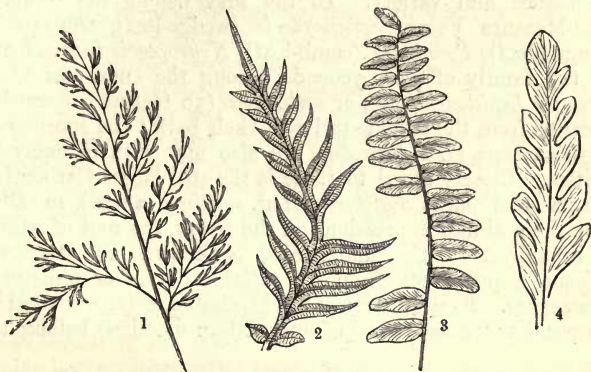


Fig. 97.—Ferns: 1, *Sphenopteris affinis*; 2, *Pecopteris lonchitica* (pinnule); 3, *Neuropteris gigantea* (pinnule); 4, *Odontopteris obtusa* (pinnule).

tropical swamps and jungles. The vast majority belonged to the Cryptogamous or flowerless division of the vege-

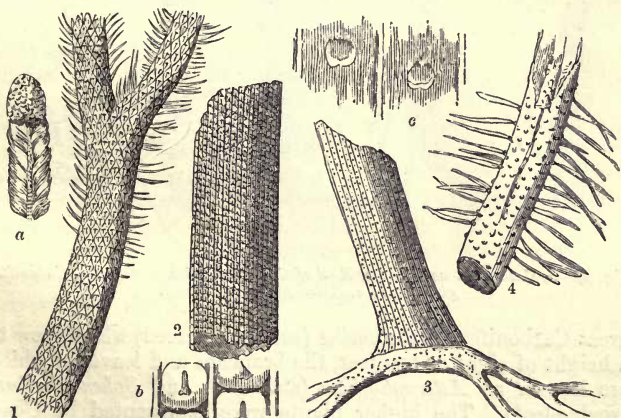


Fig. 98.—1, *Lepidodendron Sternbergii*; a, *Lepidostrobus* or cone of do. 2, *Favularia tessellata*; b, Leaf-scar of do. 3, *Sigillaria oculata*, with stigmaria roots; c, Leaf-scar of do. 4, *Stigmaria ficoides*, showing rootlets and pith.

table kingdom, only one section (the Gymnosperms) of the Phanerogams or flowering plants being represented. Each

of the three great sections of the Ferns, Equisetaceæ (horse-tails), and Lycopods (club-mosses) is represented in great abundance and variety. To the first belong the common Coal-Measure Ferns, *Sphenopteris* (wedge-leaf), *Glossopteris* (tongue-leaf), *Pecopteris* (comb-leaf), *Neuropteris* (nerve-leaf). To the family of the Lycopods belong the enormous Coal-Measure *Lepidodendrons*, or scale-trees (50 feet and upwards), so called from the scaly exterior of their bark; the spore-cases of these trees (*Lepidostrobus*) are also met with in many localities. Closely allied to these is the still larger Carboniferous tree-like plants *Sigillaria* (Lat. *sigillum*, a seal), so called from the seal-like impressions on the trunk, the root of which, so abundant in the underclays, is known as *Stigmaria* (*stigma*, a puncture), from its exterior dotted or punctured appearance. To the section of the Equisetaceæ (represented by the peculiar "horse-tails" of our modern marshes) belong the



Fig. 99.—1, *Calamites nodosus*; 2, Root of Calamite, with rootlets; 3, *Calamites giganteus*; 4, *Asterophyllites foliosus*.

great Carboniferous *Calamites* (*calamus*, a reed) which grew to a height of eight or ten feet, the branches and leaves of which are known as *Asterophyllites* (star-leaf), and *Sphenophyllum* (wedge-leaf). The higher plants were represented by *Conifers* (or cone-bearing trees), allied to our modern firs and pines), the commonest genera of which were *Dadoxylon* (pine-wood) and *Palæoxylon*. Even seeds which have been referred to these Conifers are occasionally met with, as *Trigonocarpon* (triangular fruit), small nut-like bodies, probably once sur-

rounded by a fleshy envelope, like the fruit of the modern yew.

224. Whatever the botanical families to which these extinct vegetable remains belong, they now for the most part constitute solid seams of coal—coal being a mass of compressed and mineralised vegetation, just as sandstone is consolidated sand, or shale consolidated mud. When vegetable matter is buried in wet ground, it decomposes, giving rise to carbonic acid gas, and thus losing a portion of its original oxygen. We see in peat and lignite the successive steps to such a mineralisation, and as the process is continued further other gases are given off—carburetted hydrogen, or common gas, nitrogen, &c., and the lignite becomes in turn transformed to bituminous or common coal, steam coal, and finally to anthracite. That some coals were formed on land or swampy marshes appears clear from the fact that trees are now found in the position in which they grew, while the underclay of many coal seams is filled with the roots and rootlets that supported the vegetation growing above. That much was drifted into estuaries and river shallows appears equally evident. Bark, leaves, spores—all have aided in making up the thick masses of carbon of which the coal-seams are composed. In coal itself we find in almost every parting traces of vegetable tissue; and when slices are submitted to the microscope, the organic structure is often as distinctly displayed as the cells and fibres in a piece of timber. Of the amount of vegetation required to form not only one seam, but the forty or fifty seams which often succeed each other in coal-fields, we can form no adequate conception, any more than we can calculate the time required for their growth and consolidation. This only we know, that conditions of soil and moisture and climate must have been exceedingly favourable; that over a large portion of the globe such conditions prevailed for ages; and that partly by the drift of gigantic rivers, and partly by the successive submergences of forests, jungles, and peat-swamps, the vegetable matter was accumulated which now constitutes our valuable seams of coal.

225. During the earlier portion of the Carboniferous epoch we find, as we have seen, ample evidence of *igneous activity*, but only in the Scottish area. Subsequent to the deposition of the system, it seems to have been shattered and broken up by those forces which elevated the hills of the mountain limestone, and gave birth to the numerous basaltic crags and conical heights of our northern coal-fields. These later traps

are chiefly augitic, and consist of basalts and greenstones. These upheavals and convulsions have greatly dislocated the Carboniferous strata, and most of our coal-fields exhibit trap-dykes, faults, and fissures, in great complexity and abundance. If we except the hills of the mountain limestone, some of the basaltic crags and cones, and now and then a glen of erosion cut through the softer strata of the system, the *scenery* of coal districts is on the whole rather tame and unpicturesque. The soil, too, derived from the shales and clays beneath, is in general often cold and retentive, and requires all the skill and appliances of modern agriculture to render it moderately fertile. These drawbacks, however, are more than compensated for by the value of the mineral treasures which lie beneath.

226. The industrial importance of the Carboniferous system can only be adequately appreciated in a country like Britain, which owes to it the proud mechanical and manufacturing position which she now enjoys. *Building-stone* of the finest quality is obtained from the white sandstones of the lower groups; *limestones* for mortar, hydraulic cement, and agricultural purposes, are largely quarried from the middle group, which also yields *marbles*, or rather sub-crystalline limestones, of no mean quality; *fire-clay* for bricks, tiles, pipes, retorts, &c., is extensively raised from the Coal-Measures; *iron-stone*, both blackband and clay-carbonate, is mined in almost every coal-field; *ochre* (hydrated oxide of iron) is obtained in several localities; *alum* is largely prepared from some of the shales; *copperas*, or sulphate of iron, is manufactured from the pyritous varieties; *paraffin* and *paraffin-oil* from the more bituminous varieties; and our supply of *coal*, in all its varieties, is procured solely from this system. The mountain limestone is also in this country the main repository of the ores of *lead*, *zinc*, and *antimony*, and in the same veinstones are associated ores of *silver*. On the whole, the Carboniferous system is decidedly the most valuable and most important to man; and when we name the principal coal-fields of Britain, we point at the same instant to the busiest centres of our manufacturing and mechanical industry.

227. In no country of the world, perhaps, do the Carboniferous rocks occupy so large a proportion of the entire surface as in southern Britain. The coal-fields of western and central Europe are comparatively small. The best known are those of Belgium and the north of France, of St Etienne in central France, and of Saarbruck in Germany. The Russian coal-fields afford a poor coal. In China, however, there appear to be enormous areas of coal-bearing rocks. This is also the

case in North America, especially within the limits of the United States,—the coal-basins of which occupy an area of at least 150,000 square miles. Other coal-fields occur in New Brunswick, Nova Scotia, and Newfoundland. The Carboniferous Limestone series (Sub-Carboniferous) is also magnificently developed within the boundaries of the United States, the two great divisions of the North American Carboniferous being recognisable not only by their lithological characters and systematic position, but also by their characteristic animals and plants. Indeed, the physical and biological conditions of Carboniferous time appear to have been practically the same on both sides of the Atlantic Ocean.

#### RECAPITULATION.

228. The strata we have now described constitute a well-marked and peculiar system, lying between the Old Red Sandstone beneath, and the New Red Sandstone above. Their most striking peculiarity is the profusion of fossil vegetation, which marks more or less almost every stratum, and which in numerous instances forms thick seams of solid coal. It is to this exuberance of vegetation that the system owes its name—*carbon* being the main solid element of plants and coal. Although this coaly or carbonaceous aspect prevails throughout the whole system, it has been found convenient to arrange it in two main divisions—the *Lower Carboniferous*, of which the great Mountain Limestone is the characteristic member; and the *Upper Carboniferous*, which is remarkable for the abundance and economic value of its Coal-Measures, the two being divided from each other by an intervening series of coarse sandstones known as the *Millstone Grit*. Taking the whole succession and alternations of the strata—the sandstones, clays, shales, limestones, ironstones, and coal—and noting their peculiar fossils, the estuarine character of the shells and fishes of the Coal-Measures, and the marine character of the corals, encrinites, shells, and fishes of the Limestones, and the excess of terrestrial vegetation throughout, we are reminded of conditions never before or since exhibited in this part of our globe.

229. The frequent alternations of the strata, and the great extent of our coal-fields, indicate the existence of vast estuaries and inland seas, of gigantic rivers and periodical inundations; the numerous coal-seams and bituminous shales clearly bespeak conditions of soil, moisture, and climate favourable to an exuberant vegetation, and point partly to great deltas,

and partly to submerged forests, to peat-swamps and jungle-growth; the Mountain Limestone, with its marine remains, reminds us of low tropical islands, fringed with coral-reefs, and to lagoons thronged with shell-fish and fishes; the existence of reptiles and insects tells us of air, and sunlight, and river-banks; the vast geographical extent of the system bears evidence of a more equable climate over a large portion of the earth's surface; while the interstratified trap-tuffs, the andesitic outbursts, and the numerous faults and fissures, testify to a period of intense igneous activity—to repeated upheavals of sea-bottom and submergences of dry land. All this is so clearly indicated to the investigator of the Carboniferous system, that he feels as convinced of their occurrence as if he had stood on the river-bank of the period, and seen the muddy current roll down its burden of vegetable drift; threaded the channels of the estuary, gloomy with the gigantic growth of swamp and jungle; or sailed over the shallow waters of its archipelago, studded with reef-fringed volcanic islands, and dipped his oar into the forests of encrinites that waved below. The natural conditions under which the system was formed in Britain are not more wonderful, however, than the economical importance of its products. Building-stone, flagstone, limestone, marble, fire-clay, alum, copperas, lead, zinc, silver, and, above all, iron and coal, are its principal treasures—conferring new wealth and comfort on the country that possesses them, and giving a fresh and permanent impetus to its industry and civilisation.

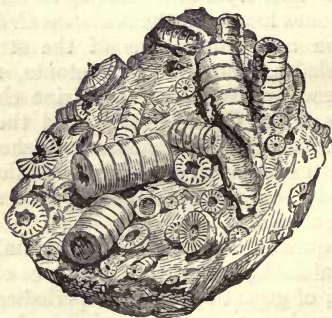


Fig. 100.—*Weathered fragment of Encrinital Limestone.*

## CHAPTER XVII.

## THE PERMIAN OR DYASSIC SYSTEM.

230. IMMEDIATELY above the Coal-Measures—in some instances overlying them unconformably, as in Yorkshire, and in others insensibly graduating from them, as in south Staffordshire—occurs a great thickness of red sandstones, yellowish magnesian limestones, and variegated shales and marls, enclosing irregular masses of rock-salt and gypsum. To this series of strata, as more especially developed in England, the earlier geologists applied the term *New Red Sandstone*, in contradistinction to the *Old Red Sandstone* system, which we have already described as lying beneath the Carboniferous formation. Though the sandstones are not all red, nor the limestones the only magnesian limestones in the crust of the earth, yet reddish hues prevail throughout the sandstones and shales, as developed in the British Islands, and the calcareous beds are certainly more eminently magnesian than any others with which we are acquainted. The terms *Poikilitic* (variegated) and *Saliferous* (salt-yielding) have been also applied to the system; but the facts that variegated marls abound in the Old Red, and that salt is found in several other systems, have rendered these designations inappropriate, and they are now rarely used. This New Red Sandstone of the earlier geologists is now usually arranged into two distinct systems, the *Permian* and the *Triassic*—the former embracing the two lower members of the collective series, which are largely developed in the government of Perm, in Russia, and which, because they are typically always two in number as in central Germany, are often known as the *Dyas*, or double group; and the latter, comprising the three upper members, known in Germany as the *Trias*, or triple group. The rea-

son for this arrangement is, that the fossils of the Dyassic or Magnesian limestone and Lower Red sandstones of Britain, and their foreign equivalents, seem more closely allied to those of the Coal-Measures beneath, than to those of the variegated sandstones and saliferous marls above which constitute the Triassic group of Germany. In other words, the Dyassic fossils present a *Palæozoic* aspect, while those of the Trias are *Mesozoic*. Indeed, many of the fossils of the Permian or Lower New Red are identical with those of the Carboniferous, and it has been questioned by some whether the so-called "Permian" ought not to be regarded as the terminal division of the Carboniferous series, rather than a separate and independent system.

231. The Permian system, as developed in England, Germany, and Russia, consists essentially of reddish, and occasionally whitish, quartzose sandstones; of reddish and variegated shales (mottled, purple, yellow, and green); of yellowish limestones, containing a notable percentage of magnesia; and of calcareous or marly flagstones, locally impregnated with copper-pyrites. The sandstones are generally thick-bedded, sometimes gritty, but rarely conglomeratic on the large scale, though frequently containing pebbles and intercalated bands of pebbly conglomerate. The shales are usually called "marls," but this less from their containing any notable quantity of lime, than from their occurring in a mottled, friable, and non-laminated state. The limestones vary from an almost pure carbonate of lime to an admixture containing upwards of forty per cent of carbonate of magnesia—hence called "magnesian limestones." Their structure is often peculiar, occurring in thick beds, with subordinate concretionary zones, finely-laminated strata, and layers of a powdery nature. These concretions are frequently of curious shapes—*honeycombed*, *mammillary* (or pap-like), *botryoidal* (or in clusters like a bunch of grapes), and *coralloid*, or so mimetic of coral-growths as at first sight to be mistaken for them. When the magnesian limestone assumes a granular and crystalline texture, it is known by the mineralogical name of *dolomite*, after the French geologist, M. Dolomieu. The slaty or flaggy beds are known in England as "marl slates"—and in Germany, where they are largely impregnated with copper-pyrites, as "kupfer-schiefer" (copper-slate),—names now quite familiar to British geologists.

232. With respect to the order of succession among the Permian, we find, as in the Old Red Sandstone and Devonian

period, two distinct lithological types. In the districts of central Germany we find the system separable into two main members (Dyassic type): viz., a lower series of red sandstones and conglomerates, and an upper series of limestones, dolomites, and shales. In Russia the strata of this age are composed of a mixed series of sandstones, marls, limestones, and thin coals (Permian type). In Britain both types are apparently represented—the Dyassic type on the east, and the Permian type on the west of the Pennine chain and its southern extension. The following is a generalised table of the strata as exhibited in Yorkshire, Durham, and Nottingham—

**B. MAGNESIAN LIMESTONE SERIES.** 600 to 700 feet.

*Laminated Limestone*, with layers of coloured marls, as at Knottingley, Doncaster, &c.

*Gypseous Marls*—Red, bluish, and mottled.

*Magnesian Limestone*—Yellow and white; of variable texture and structure; some parts, as at Tynemouth, brecciated, or made up of fragmentary masses.

*Marl Slates*—Laminated, impure calcareous flagstones of soft argillaceous or sandy nature.

**A. RED SANDSTONE SERIES.** 3 to 250 feet.

*Red Sandstones*, with red and purple marls, and a few micaceous beds. The grits are sometimes white or yellow, and pebbly, and rest unconformably upon the Coal-Measures below.

On the western side of the Pennine range, near Appleby, the magnesian limestone is apparently represented by a calcareous band with shales and impure coals, only 55 feet in thickness, and is overlain by 750 feet of red sandstones and shales, and is underlain by 550 feet of red sandstones and breccias. As we pass north and south of this area, the limestones disappear, and the whole group is formed of masses of red sandstone and shales, which occur in many isolated patches, as near Carlisle, where they reach the thickness of 3500 feet; in the valley of the Nith, near Dumfries, &c., &c., resting unconformably on the rocks below. In Flintshire, Shropshire, and south Staffordshire, they usually graduate upwards from the Carboniferous conformably; in the last two localities the central member of the system is a *coarse breccia*, 400 feet in thickness, formed of angular fragments of volcanic rocks, and resting upon a group of sandstones, with calcareous *cornstones* like those of the Old Red formation.

233. In Germany the Dyassic type of the rocks of this system attains its typical development along the flanks of the Harz Mountains, and in Saxony and in Bavaria, where the complete sequence is as follows—

**B. ZECHSTEIN OR UPPER DYASSIC.**

The typical member of this division is the *Zechstein* itself—a magnesian limestone, having a band of black shale below (the rich kupfer-schiefer, or copper-slate, of central Germany) and a series of limestones, dolomites, and marls above.

**A. ROTHLIEGENDE OR LOWER DYASSIC.**

Thick red conglomerates, sandstones, shales, and breccias, resting unconformably upon the Carboniferous rocks, and containing thick masses of contemporaneous volcanic rocks, andesites, basalts, and tuffs.

234. The *Organic remains* of the Permian System, as we have already indicated, present us with a continuance of the

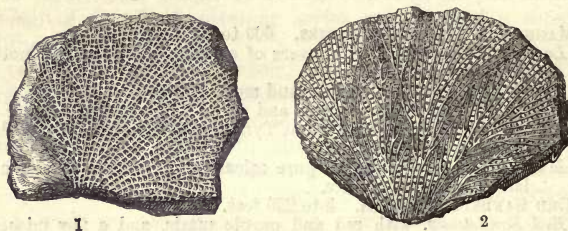


Fig. 101.—1, *Fenestella retiformis*; 2, *Synocladia virgulacea*.

Palæozoic facies of those of the underlying carboniferous system. In the Magnesian Limestone the commonest forms

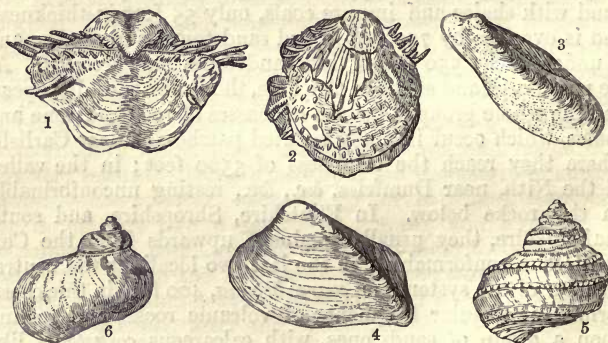


Fig. 102.—1, *Productus horridus*; 2, *Strophalosia Morrisiana*; 3, *Bakevellia Sedgwickiana*; 4, *Schizodus Schlotheimii*; 5, *Turbo helycinus*; 6, *Natica Leibnitziana*.

are Polyzoa, of the group of the “lace-corals” (*Fenestella retiformis*, *Synocladia virgulacea*), Lamellibranchs or bivalves

(*Bakevellia tumida*, *Schizodus Schlotheimii*), and a few Brachio-poda (*Productus horridus*, *Lingula Credneri*, *Strophalosia Goldfussi*). Of the Vertebrata of Permian time we find not only examples of Fishes and Amphibians, but we meet with true Reptiles for the first time in the geological record. The Fishes all belong to the heterocercal Ganoids (*Platysomus*

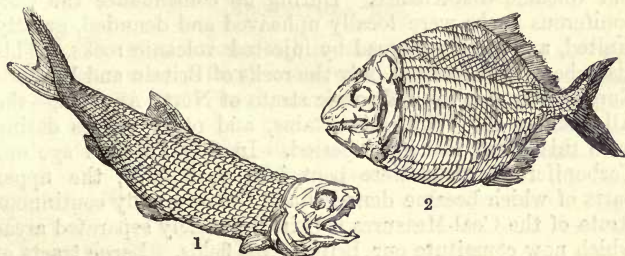


Fig. 103.—1, *Palæoniscus Frieslebeni*; 2, *Platysomus striatus*.

*striatus*, *Palæoniscus Frieslebeni*): the Amphibia are still Labyrinthodonts (*Dasyceps Bucklandi*): the Reptiles are *Protorosaurus Speneri* (from the German *Kupfer-schiefer*) and *P. Hanleyi*. The plants of the Permian period, although their species are distinct from those of the Carboniferous, yet agree with them generically; we find species of *Neuropteris*, *Sphenopteris*, and *Annularia*, *Lepidodendrons* and *Calamites*; but the common Carboniferous genera, *Sigillaria* and

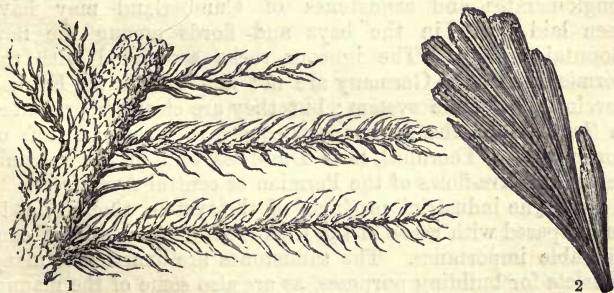


Fig. 104.—1, *Walchia piniformis*; 2, *Næggerathia cuneifolia*.

*Stigmaria*, appear to be wanting. The forms most characteristic of the Permian rocks are—*Walchia* (*W. piniformis*) and *Ullmannia* (*U. selaginoides*); Conifers which bear true

cones, and a remarkable tree-fern known as *Psaronius*, whose trunk, like that of some of its modern relations, was surrounded by a dense mass of air-roots. The silicified trunks of this last-named form are common in some areas of the German Dyas.

235. The Permian period was one of great earth-movement and volcanic disturbance. During its continuance the Carboniferous rocks were locally upheaved and denuded, greatly faulted, and locally pierced by injected volcanic rocks. This disturbance affected not only the rocks of Britain and Western Europe, but also the Palæozoic strata of North America,—the Alleghanies, the White Mountains, and other ranges dating from this great elevatory period. In this Permian age our Carboniferous rocks were bent into vast folds, the upper parts of which became denuded and the originally continuous strata of the Coal-Measures left in the widely separated areas which now constitute our British coal-fields. Large tracts of country were cut off from the ocean, and inland seas, comparable with that of the modern Caspian, were formed. One of these must have extended across a part of the present German Ocean eastward from the Pennine area, and in this sea the Magnesian Limestone of York and Nottingham was probably deposited. To the west and south much of the new land appears to have been steep and rugged, and probably of a height sufficient to nourish vast glaciers. The great Permian breccias of the Western Midlands have many of the ordinary features of a glacial deposit; the thick Permian conglomerates and sandstones of Cumberland may have been laid down in the bays and fiords among the new mountain-ranges. The igneous rocks associated with the Permian strata in Germany are not met with in the English development of the system; but they are clearly represented in Scotland in the contemporaneous lava-flows and tuffs of porphyrite of Thornhill, near Dumfries, and in the volcanic necks and lava-flows of the Permian of central Ayrshire.

236. The industrial products of the system, though not to be compared with those of the Coal-Measures, are still of considerable importance. The sandstones are quarried in many districts for building purposes, as are also some of the magnesian limestones (Durham and Yorkshire), which dress well, are often exceedingly durable, and have been employed in the construction of some of our chief cathedrals and public buildings. The limestones are likewise used in agriculture, and for the extraction of magnesia; while certain of

the compact varieties found in Germany furnish blocks for lithographic printing. Gypsum is an abundant product of some of the marls; while in Germany the *Kupfer-schiefer* has been long mined as an ore of copper, and furnishes a large proportion of that valuable metal.

## RECAPITULATION.

237. The system described in this chapter consists of reddish sandstones, yellowish magnesian limestones, and shaly calcareous beds and conglomerates. By the earlier geologists it was looked upon simply as the lower division of the New Red Sandstone; but the saliferous marls and shelly limestones of the upper division of that great formation having been subsequently proved to contain a fauna closely allied to that of the Neozoic fauna of the overlying Jurassic rocks, and the lower division to yield fossils of the same Palæozoic type as that of the underlying Carboniferous, the two divisions have been separated as distinct systems. To the lower system the name of Permian has been applied by the English, because of its wide and complex development in the Russian district of Perm. In Germany it is known as the *Dyas* (or twofold system), from the fact that it is there always divisible into a lower or sandy member (*Rothliegende*), and an upper or calcareous member (*Zechstein*). In Britain both the Russian and German types are represented—the one on the east of the Pennine range, the other mainly to the west. In the Yorkshire basin the Permian consists of two members (the Lower Permian or Red Sandstone, and the Upper Permian or Magnesian Limestone group); in Cumberland and elsewhere, mainly of massive red sandstone and breccias, with an occasional intermediate zone of red clays or calcareous beds. The Permian period was one of remarkable earth-movement in some areas, and of great igneous activity in others. During its progress the Coal-Measures were upheaved, folded, and denuded, and left in the general form of our present coal-fields; large water areas were cut off from an outlet to the ocean, to form brackish inland seas and salt-water lakes. The life of the period was essentially Palæozoic: the corals, the brachiopods, and the mollusca belong to Carboniferous genera; the fishes to the ancient group of the Ganoids; and most of the plants appertain to the same genera as those of Carboniferous time. Two new groups, however, make their first appearance in the system—the true cone-bearing trees

and the great class of the reptiles. As regards scenery, the districts occupied by the Permian rocks show a fair amount of surface diversity, the magnesian limestone of Durham often standing up in isolated hills of circumdenudation, and the breccias of Stafford and Salop forming well-marked hill-ranges. The soil is of medium quality, and affords rich verdant pastures, rather than arable land for mixed husbandry. Industrially the system yields building-stone, limestone, gypsum, copper, and frequently valuable seams of coal, as in Flintshire, France, and Bohemia.

## SECTION IV.—THE MESOZOIC PERIOD.

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### CHAPTER XVIII.

#### TRIASSIC SYSTEM.

238. WE have now passed the boundary of the lower or Primary rocks, and we enter upon the upper or so-called Secondary formations. We have traced the history of the systems whose organic remains are all of *Palæozoic* types, and we now proceed to interpret the records of those which are *Neozoic*. The curious *Graptolites* and *Trilobites* that crowded the Proterozoic seas have vanished, most of the bone-cased Ganoids of the Deuterozoic have practically died away, and the *Sigillarias* and *Lepidodendrons* that thronged the jungles of that period have become extinct. Their places are taken by other forms of plants and animals,—forms still widely different from existing races, yet much more akin to them than were those of Palæozoic times. The first three systems that belong to these Neozoic rocks form a special cycle of their own, both physically and biologically. They are grouped by the geologist as *Secondary* because of their systematic position; while the sub-period in which they were deposited is denominated *Mesozoic*, from the fact that their collective fauna is intermediate in character between that of Palæozoic ages and that of Recent times. These Secondary or Mesozoic rocks, like those of the Deuterozoic period we have last investigated, fall into three systems—the *Triassic* (from the threefold division of its sediments in the typical areas); the *Jurassic* (from the magnificent development of these rocks in Jura ranges of Europe); and the *Cretaceous* (from the circumstance that the well-known chalk formation of Britain and

western Europe forms its most conspicuous member). The life of the Mesozoic age was remarkable for the abundance, the variety, and giant size of its *Reptiles*; for the first appearance of the true *bony Fishes*, of *Birds*, of *Mammals*, and of *Dicotyledonous* plants and trees.

239. The first of the three systems of the Secondary or Mesozoic rocks attains a wide geographical extent in England; but the typical development of the system is found in central Germany, whence it has derived its name of the Trias. In that typical area we have the following sequence—the lowest beds resting unconformably on the rocks of the more ancient systems :—

#### UPPER TRIAS OR KEUPER SERIES.

Red marls and beds of gypsum and rock-salt, overlying sandstones, marls, and clays, with thin coals (1200 feet). Fossils, *Equisetum columnare*, *Voltzia heterophylla*, *Mastodontosaurus Jägeri*.

#### MIDDLE TRIAS OR MUSCHELKALK (shell limestone).

Thick beds of limestone and dolomites, filled with crinoid stems (500 feet). *Encrinurus liliiformis*, *Ceratites nodosus*.

#### LOWER TRIAS OR BUNTER (variegated).

Red and green marls, thick beds of coarse sandstones. *Estheria minuta*, *Myophoria costata*.

In Britain the middle division or Muschelkalk of Germany is wanting, only the Upper or Keuper, and Lower or Bunter divisions being represented, as shown in the following table :—

#### UPPER TRIAS OR KEUPER.

(5) *Keuper Marls*—red and green marls, with occasional sandstones, beds of gypsum, and local layers of rock-salt (700 to 3000 feet). *Estheria minuta*, *Hyperodapedon*.

(4) *Waterstones, or Lower Keuper Sandstone*—red and white sandstones, and occasional conglomerates (150 to 400 feet).

#### LOWER TRIAS OR BUNTER.

(3) *Upper Mottled Sandstones*—soft red and variegated sandstones and marls (0 to 500 feet).

(2) *Pebble Beds or Triassic Conglomerate*—thick beds of rounded pebbles (generally formed of quartzite), with local sandstones (0 to 750 feet).

(1) *Lower Mottled Sandstones*—soft red sandstones and marls (0 to 500 feet).

240. These Triassic beds extend over a large area in central England, resting unconformably upon all below, but having their highest members covered up conformably by the lowest strata of the succeeding system. They range also north-

eastward to the mouth of the Tees, north-westward to Lancaster and the basin of the Solway, and south-westward to the mouth of the Exe. As will be seen from the foregoing description, they vary greatly in thickness. Each reposes unconformably upon the older rocks in its turn, the intermediate beds being locally absent. They attain their maximum extent in Cheshire, where all the beds are present and at their thickest; but thin away and disappear one below the other to the south-east, until in Leicester the Keuper rests at once on the old rocks. Triassic strata also occur in Morayshire and elsewhere in north-east Scotland, where they were for many years regarded by some geologists as belonging to the Old Red Sandstone, until the discovery within them of undoubted triassic fossils (*Hyperodapedon*, &c.) A thin but fairly complete representation of the Trias occurs also in north-east Ireland, near Belfast. Except in Devonshire, where there occur some well-marked contemporary igneous rocks (related to the mica traps or minettes), the Triassic, like all the British Mesozoic systems, are wholly free from volcanic rocks.

241. Scenically the predominance of clays and shales and soft sandstones gives rise to broad level expanses, rather tame and uninteresting in their superficial features. "Spread over so immense a space in England," observed Professor Phillips, "the Triassic system offers the remarkable fact of never rising to elevations much above 800 feet—a circumstance probably not explicable by the mere eroding of these soft rocks by floods of water, but due to some law of physical geology yet unexplained. We only can conjecture that it is connected with the repose of subterranean forces which prevailed after the violent commotions of the coal strata, over nearly all Europe, till the tertiary epoch." In general, Triassic districts, from the weathering down of their marls into a stiff retentive clay, are better fitted for pasture and dairy husbandry than for the purposes of mixed husbandry or corn-culture.

242. The industrial products yielded by the system are sandstones of various quality, calcareous flagstones, limestone, gypsum, and rock-salt. Our chief supply of salt, formerly obtained by evaporation of sea-water, is now procured from the salt-mines and brine-springs of Cheshire and Worcester. According to the authority already quoted, "the Cheshire deposits of salt lie along the line of the valley of the Weaver, in small patches, about Northwich. There are two beds of

rock-salt lying beneath 126 feet of coloured marls, in which no traces of animal or vegetable fossils occur. The upper bed of salt is 75 feet thick; it is separated from the lower one by 30 feet of coloured marls, similar to the general cover; and the lower bed of salt is above 100 feet thick. They extend over an irregular oval area, about a mile and a half in length, by three-quarters of a mile in breadth." The salt-rock in these deposits—as likewise at Middlesborough on the Tees, in Antrim, at Würtemberg in Germany, and at Vic and Dieuze in France—is sometimes pure and transparent, and at other times is of a dirty-reddish hue, and mixed to the amount of half its bulk with earthy impurities.

243. When we turn to the fossils of the system we find the Plants of the Coal and Permian epochs represented only by a few ferns (*Pecopteris*, *Cyclopteris*); the place of the calamites of the Coal is taken by horse-tail reeds (*Equisetum columnare*). The Conifers are represented by *Voltzia* (*V. heterophylla*). But the most remarkable Triassic plants belong to the group of the *Cycads*, a group related to the pines and firs, but somewhat resembling young palms in appearance, and repre-



Fig. 105.—1, *Walchia diffusus*; 2, *Pterozamites linearis*.

sented nowadays by the Australian *Zamia*, &c. These make practically their first appearance in the Trias, where we find the genera *Pterophyllum* and *Podozamites*, &c. There are

few corals, but crinoids occur abundantly in the German Muschelkalk (*Encrinus liliiformis*), and Star-fish (*Aspidura loricata*). Of the Brachiopods, *Terebratula* and *Spirifer* are

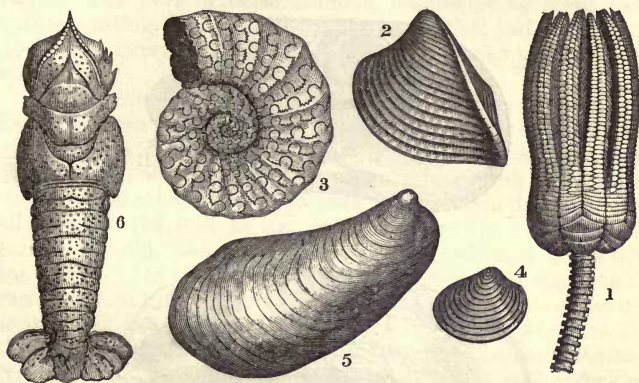


Fig 106.—1, *Encrinus liliiformis*; 2, *Myophoria lineata*; 3, *Ceratites nodosus*; 4, *Estheria minuta*; 5, *Plagiostoma obliqua*; 6, *Pemphix Sueurii*.

present, but the *Productus* of the Palæozoic has disappeared. Of Lamellibranchs, there are many forms; and of the Cephalopoda, or highest group of Molluscs, we have the striking genus *Ceratites* (*C. nodosus*), which is confined to Triassic strata in European countries. Of Articulata, we have the curious Crustaceans, *Estheria* (*E. minuta*), and *Pemphix*. Of the Vertebrata we find fishes, ganoid (*Palæoniscus* and *Catopterus*), placoid, and dipnoid—the last section being represented



Fig 107.—A, Dental plate of *Ceratodus serratus*, Keuper; B, Dental plate of *Ceratodus altus*, Keuper. (After Agassiz).

by *Ceratodus serratus*, &c., forms closely allied to the extraordinary vegetable-feeding Mud-fish (*Ceratodus Fosteri*) of Queensland. The Amphibians are represented by the curious

order of the *Labyrinthodonta* (so named from the convoluted structure of their teeth), of which *L. Jägeri* of the Keuper is the best-known Triassic example. The Reptilia of the

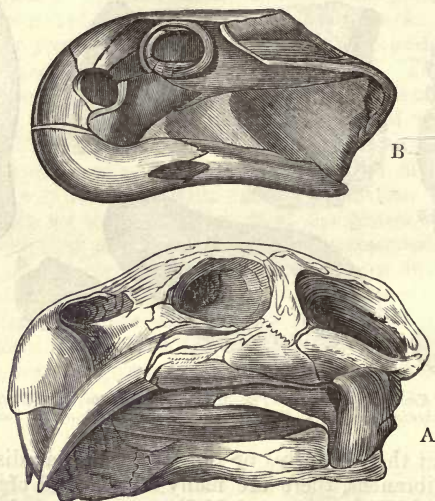


Fig. 108.—Triassic Anomodont Reptiles. A, Skull of *Dicynodon lacerticeps*, showing one of the great maxillary tusks; B, Skull of *Oudenodon Bainii*, showing the toothless, beak-like jaws. From the Trias of South Africa. (After Owen.)

system are especially remarkable. They belong to the group of the *Sphænodonta* or beaked lizards, which is typified by

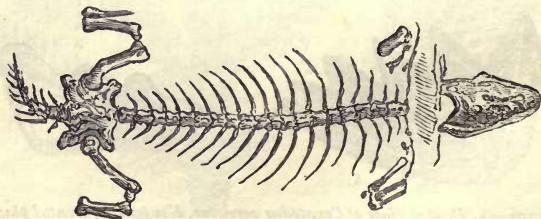


Fig. 109.—*Telerpeton Elginense*.

the curious living *Sphenodon* of New Zealand. To this group belong the *Hyperodapedon Gordoni* of the Triassic sandstones of Elgin and Warwick, and the *Rhyncosaurus* of

the Trias of Shrewsbury. Closely allied to these are the small lizard-like *Telerpeton Elginense*, and the strange *Dicynodonts* or two-tusked reptiles of the Trias of South Africa and India. The jaws of these animals, besides being furnished with a cutting edge, like those of the turtles, had a pair of downward curving tusks in the upper jaw, like those of the walrus.

244. Besides the teeth and bones of these early reptiles, we have also their footprints impressed and preserved on the slabs of sandstone, almost as clearly as if they had traversed the muddy beach of yesterday. These footprints speak a language similar to that of the ripple-mark and the rain-drop already alluded to—the foot leaving its impress on the yielding and half-dried mud, and the next deposit of sediment filling up the mould. On splitting up many of these slabs of sandstone, the mould and its cast are found in great perfection—so much so, that not only the joints of the toes but the very texture of the skin is apparent. These fossil footprints, termed *ichnites* (Gr. *ichnon*, a footstep), have been largely found at Corncockle Muir in Dumfriesshire, at Cummington in Morayshire (the Lossiemouth sandstones), at Storeton in Cheshire, and elsewhere. The annexed engraving (fig. 110) represents the footsteps of the *Cheirotherium* (*cheir*, the hand), so called from



Fig. 110.—Footprints of *Cheirotherium* or *Labyrinthodon*.

the hand-like impressions of its feet, and supposed by Professor Owen to be one and the same with the newt-like *Labyrinthodon*. The arenaceous British series has thus furnished only *Estheria*, the *Reptilia*, and *Amphibia*. The German *Muschelkalk* is rich in organic remains, but even these by no means represent the abundant animal life of Triassic times. In the district of the eastern Alps, at Hallstadt, and St Cassian, there is a magnificent development of highly fossiliferous Triassic rocks. Unlike the coarse inland deposits of Britain, or those of the shallow bays of the German Trias, these Alpine strata represent the complete marine type of Triassic times; and their fauna, as might naturally be expected, shows a complete admixture of Palæozoic and Neozoic

types—the *Orthoceratites*, *Murchisonias*, and *Euomphalus* of the Palæozoic ages being found in the same beds with the *Ammonites*, *Carditas*, and *Oysters*, so characteristic of rocks of Mesozoic times.

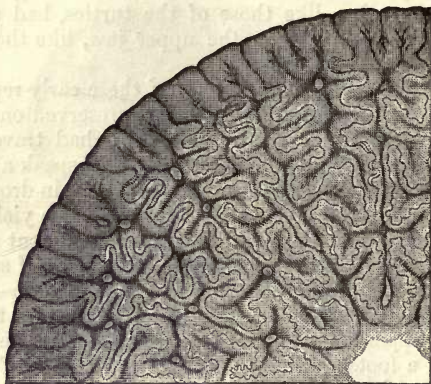


Fig. 111.—Section of the tooth of *Labyrinthodon* (*Mastodonsaurus*) *Jägeri*, showing the microscopic structure. Greatly enlarged. Trias.

#### RHÆTIC OR PENARTH SERIES.

245. At the summit of this Alpine Trias we find a thick series of fossiliferous strata—the so-called *Rhætic Series* (named after the Rhætian Alps of that region), consisting of about 1400 feet of dolomites, limestones, and shales. This forms a *transitional series* between the Triassic and the overlying Jurassic, and is arranged by geologists sometimes in one of these systems, sometimes in the other. They contain a rich suite of fossils, of which perhaps the most characteristic in their representative rocks are the Lamellibranchs, *Avicula contorta*, *Pecten Valoniensis*, and *Cardium Rhæticum*. These Rhætic strata are also found in Britain, remarkably diminished in thickness, but still containing the characteristic fossils named above. Known as the *Penarth* or *Avicula contorta* beds, and rarely exceeding 80 feet in thickness, they extend across the south of England from Axmouth (Dorsetshire) to the mouth of the Severn, and thence in local patches to the coast of Yorkshire, near Redcar. A curious fossiliferous stratum, known as the *Bone bed*, occurs among the black and green shales and white calcareous rocks of

which this little English group is composed, as at Aust, near Bristol, and elsewhere, abounding in the bones of saurians and fishes. A corresponding bed is met with also in North

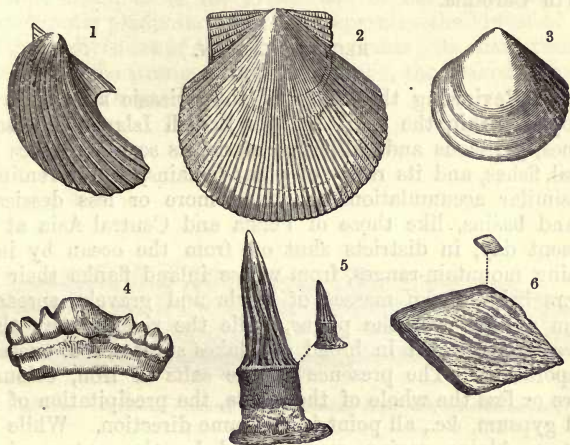


Fig. 112.—1, *Avicula contorta*; 2, *Pecten Valoniensis*; 3, *Cardium Rhæticum*; 4, *Hybodus plicatilis*; 5, *Saurichthys apicalis*, nat. size and enlarged; 6, *Gyrolepis tenuistriatus*, nat. size and enlarged. From the Rhætic Beds.

Germany. This bed is famous more especially for having afforded the remains of a warm-blooded quadruped—the earliest of its kind yet detected in the Old World. It appears to have been a small mammal of the group of the Marsupials or pouched animals. The teeth of the first example were detected in Germany in 1847; and the animal was named by

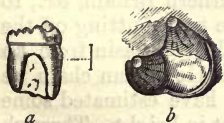


Fig. 113.—a, Molar tooth of *Microlestes antiquus*, magnified; b, Crown of the same, magnified still further. Trias, Germany.



Fig. 114.—Jaw of *Dromatherium sylvestre*, from the Red Sandstones of North Carolina. (Emmons.)

its discoverer *Microlestes antiquus* (Gr. *micros*, little; *lestes*, a beast of prey). It was, however, probably a plant-eating animal. A tooth of a similar animal (*Hypsiprymnopsis*) has

been more recently discovered in the Rhætic marls of Somersetshire. In North America, a still older form of Marsupial (*Dromatherium*) has been met with in the Triassic beds of North Carolina.

#### RECAPITULATION.

246. Reviewing the whole of the Triassic system as developed within the limits of the British Islands—its sandstones, gypseous and saliferous marls, its scanty reptiles and fossil fishes, and its rarity of plant remains, we are reminded of similar accumulations found in more or less dessicated inland basins, like those of Persia and Central Asia at the present day, in districts shut off from the ocean by intervening mountain-ranges, from whose inland flanks their few rivers bring down masses of sands and gravels, spreading them abroad over the plains, while the river waters themselves are collected in broad salt lakes subjected to excessive evaporation. The presence of the salts of iron, colouring more or less the whole of the strata, the precipitation of salt and gypsum, &c., all point in the same direction. While the eastern Alpine region was washed by the waters of the open sea, and the Muschelkalk was laid down in a German Adriatic, the British Trias must have been deposited under what were practically inland and continental conditions. But while the Permian period marks more especially the period of *upheaval* of this continent, the Triassic marks its *continuance* and slow erosion and *depression*. To the north lay the older Scandinavian range, extending through the north of Scotland and north-west of Ireland far into the present Atlantic. To the south was the newer (Permian) Hercynian chain, extending from the Harz through the Ardennes and Southern Britain, &c., to meet the Scandinavian range beyond, the two shutting off the rain-bearing winds, and cutting off the British basin from an outlet to the sea. Of the elevation of this Hercynian chain we know little; but the Belgian geologists have estimated some of its peaks at from 12,000 to 20,000 feet in height. Through all the Upper Triassic and succeeding Mesozoic times, the erosion and depression of the Hercynian ranges appears to have gone on, until they became finally submerged below the sea-waters of the great ocean-like basin in which the Chalk was laid down.

247. The Triassic system of Europe thus affords three local types of sediment and of fossils—the reef-like marine type of

the Alpine Trias, the broad-gulf type of central Germany, and the continental type of Britain. Its fauna is remarkable as being the first of truly Mesozoic character, and as affording the first examples of the great class of the Mammals. Its characteristic plants include Gymnosperms—the lowest of the two great divisions of the Flowering plants; its characteristic animals are the strange lizard-like reptilia, the beaked *Hyperodapedon* and *Dicynodonts*.



Fig. 115.—*Ceratodus Fosteri*, the Australian Mud-fish, reduced in size.

## CHAPTER XIX.

### THE JURASSIC SYSTEM.

248. THE system we have next to describe consists, as developed in England, France, and Germany, of two well-marked groups of strata, the *Lias* and the *Oolite*. Indeed, so clearly defined are these groups that they are sometimes looked upon as distinct systems; but the general similarity of the lithological features of the rocks, the striking unity in character of the collective fauna, and the evidences that the component strata in Western Europe afford of having been deposited in one grand geological period, and in one and the same physical and biological province, have gradually led to the adoption of the view that they are most naturally regarded as forming a single system, which, from its magnificent development in the Jura ranges, has received the name of the *Jurassic*. In Britain the old names of *Oolite* and *Lias* are still retained for the two divisions of the system; but in north-west Germany and elsewhere the *Jurassic* is separated into three sections, Lower, Middle, and Upper—the first alone answering to the English *Lias*. The *Lias* of the British Islands, the name of which is said to be a provincial corruption of the word *layers*, “is an alternation of thin beds of blue or grey limestone, with a light-brown weathered surface, separated by dark-coloured argillaceous partings; so that the quarries of this rock at a distance assume a striped and ribbon-like appearance.” The *Oolite* division is much more varied, consisting of alternations of massive zones of hard calcareous rocks, and thick sheets of soft grey clays, more or less calcareous. It derives its name from the rounded concretionary grains which compose many of its limestones—these grains resembling the roe or eggs of a fish (Gr. *oon*, an

egg; *lithos*, a stone). *Oolite* is the general term, though many of its limestones are not oolitic: *roestone* is sometimes employed when the grains are very distinct; and *pisolite*, or peastone (*pisum*, a pea), when the grains are large and pea-like. The peculiar roe-like grains which constitute the oolitic texture, consist either entirely of carbonate of lime, or of an external coating collected round minute particles of sand, shells, corals, &c.; the grits are composed of fragments of shells, coral, and sand; and many of the strata have a brecciated aspect, and are hence known as *ragstones*.

The following table affords a general idea of the Jurassic strata as developed in the south-west of England—the lower strata resting conformably on the Rhætic below, while the higher strata are overlapped by the various members of the succeeding Cretaceous:—

#### 249. OOLITIC FORMATIONS.

*Upper or Portland Oolites*, including the—

- (c) *Purbeck beds*, marls, fresh-water limestones, and shales, with *Cypris Purbeckensis* and lacustrine shells.
- (b) *Portland beds*, coarse and fine-grained oolitic limestones, marls, and sand; *Cerithium Portlandicum*, *Trigonia gibbosa*.
- (a) *Kimmeridge Clay* and shale, black bituminous shales and calcareous clays; *Ammonites biplex*, *Exogyra virgula*.

*Middle or Oxford Oolites*—

- (b) *Corallian*, formed of the upper and lower *Calcareous Grit* with the intermediate *Coral Rag*, with *Cidaris florigemma*, *Ammonites perarmatus*.
- (a) *Oxfordian*, formed of the *Oxford Clay* and *Kelloway Rock* (fossiliferous calcareous sandstone). Characteristic fossils, *Ammonites Jason*, *Ammonites Calloviensis*, *Belemnites hastatus*; Reptiles, *Ichthyosaurus*, *Plesiosaurus*, &c.

*Lower or Bath Oolites*—

- (b) *Great Oolite Series*, including in its upper portion the *Cornbrash* clays and calcareous sandstones, and *Bradford Clay* and *Forest Marble*. Fossils, *Apiocrinus Parkinsoni*, *Ammonites macrocephalus*. In its lower portion it is made up of the *Great Oolite* proper (thick cream-coloured limestones), *Fuller's Earth* (clays formerly employed for fulling or cleaning cloth), and the *Stonesfield Slate* (thin-bedded limestones, formerly employed for roofing purposes). The fossils of the *Great Oolite* include *Trigonia Goldfussi*, *Terebratula digona*; those of the *Stonesfield Slate* are principally Marsupial remains—*Amphitherium Prevostii*, &c.
- (a) *Inferior Oolite Series*, consisting of the *Fuller's Earth* (marls and clays), and the *Inferior Oolite Limestones* and *Grits*. Fossils, *Ammonites Parkinsoni*, *A. Humphresianus*.

## LIASSIC FORMATIONS.

*Upper Lias Clays*—clays, shales, limestones, and calcareous grits;  
*Ammonites opalinus*, *A. communis*.

*Middle Lias or Marlstone*, argillaceous limestones (with micaceous clays and sandy beds); *Ammonites spinatus*, *A. margaritatus*.

*Lower Lias Clays*—blue clays, shales, and thin bands of limestone;  
*Ammonites oxynotus*, *A. Bucklandi*, *A. planorbis*, *Lima gigantea*,  
*Gryphæa incurva*.

250. These Jurassic rocks stretch across England from the shores of the English Channel between Portland and Lyme Regis, through the counties of Dorset, Wilts, Gloucester, Warwick, Northampton, Lincoln and south-west Yorkshire, to the coast of the German Ocean between Flamborough Head and the Tees. In this range they vary greatly both in thickness and in lithological characters. The Lias varies least, being 1400 feet thick in Dorset and 1000 feet in south-west Yorkshire, where it contains a valuable bed of carbonate of iron largely worked in the districts of Cleveland. The Lower Oolites vary from 900 feet in Dorset to 50 feet in the Midland counties, expanding again to nearly 500 feet in north-east Yorkshire. In the south-west part of their range they are marine limestones and clays; in the central part they consist both of marine limestones (*Lincolnshire Limestones*) and estuarine sandstones rich in iron ore (*Northampton Sand*), while at the extreme north-east in Yorkshire they are all practically of estuarine origin. The strata of the Middle Division of the Oolites are somewhat less variable. The Oxford division varies from about 800 feet in Dorset to 430 feet in Yorkshire. Its rocks appear to be always of marine origin. The strata of the highest, or Portlandian division, are best developed along the shores of the English Channel, where they are from 1300 to 1500 feet in thickness. The Purbeck beds occur only in this locality, and show evidence of the coming on of the estuarine and fresh-water conditions of the succeeding *Wealden*. Inland, the beds of the Portlandian division are only seen in isolated patches emerging from below the overlying Cretaceous. In Scotland the Lias is represented in the Western Hebrides, in the islands of Mull, Skye, and Raasay, rising from below the great sheets of basalt of that region. The strata attain a collective thickness of 1200 feet, and contain the characteristic fossils of the English Lias. They are succeeded by limestones and sandstones, answering to the Inferior Oolite, and the series is terminated by an *estuarine* series of limestones, sandstones,

and black shales, representing the group of the Great Oolite. On the shores of the Moray Firth the Trias with *Hyperodapedon* is followed by a thickness of 500 feet of estuarine deposits of the age of the English Lower Lias. Estuarine beds of Great Oolite age also occur in that area, the largest of which (Brora, Sutherland) is so rich in plant remains that it has been worked for coal. The Jurassic beds of England cross the Channel, and are found again in full sequence in north France and the Jura, and in broad areas along the Alpine ranges and their flanks. Corresponding rocks occur in north Germany, north Russia, and even in Spitzbergen; while in India the great coal-bearing Gondwana series of that country may be in part of Jurassic age. In North America, in the Rocky Mountains, Greenland, and elsewhere, Jurassic beds have been met with, also in Australia and New Zealand.

251. The English districts overspread by the Jurassic rocks have a marked character of their own—the out-cropping limestones giving origin to a series of long ridges, the clays between forming the subsoil of parallel valleys or wide corn-bearing plains. Few of the ridges are of great height, the chief being the range of the Cotswolds, formed by the thick limestones of the Inferior Oolite. The soils of these ridges are usually dry and fertile, and often present a marked contrast to the stiff soils formed by the intervening clays. Many of the Lias marls, however, weather into soils of great thickness and fertility. Industrially, the system is of great importance. Some of the Oolite limestones, like those of Bath and Portland, form excellent building-stones, and are largely used in the metropolis and other large towns. The limestones of the Lias and Oolite are largely quarried; those of the former, when well prepared, furnishing an excellent hydraulic cement. Ornamental limestones, or so-called marbles, of various quality, are procured from the Purbeck, and also from some of the coralline and shelly Oolites, as at Whichwood forest in Oxfordshire, whence the term “Forest marble.” Lithographic slabs are also procured from the limestones of the system—the finest known being those from Germany. Fuller’s earth, at one time extensively used in woollen manufacture, is a product of the Oolite, and alum is (or rather at one time was largely) obtained from the Lias shales of Yorkshire. In Swabia, petroleum occurs in the Upper Lias marls in such abundance as to be used for the preparation of paraffin-oil—a use to which the Kimmeridge Clay of our own Upper Oolite has long been applied. Seams of coal,

which are often workable, occur in the Jurassic, as in Yorkshire, at Brora in Sutherlandshire, at several places in Germany, in India, and other localities. Indeed, many foreign coal-fields are now known to be of Oolitic origin, or at all events to be of Mesozoic or Secondary age, and later than the true Carboniferous era. Jet, which is only a compact variety of coal, and lignite or wood-coal, are both found in the system—the former being of considerable economic value. And lastly, the ironstones of Northamptonshire, and of Cleveland in Yorkshire, which occur in thick beds, and over a large extent of country, have added new industrial importance to the system.

252. The organic remains of the Jurassic system are remarkable for their abundance, their excellent state of preservation, and their great variety; and they have long engaged the attention of palæontologists and biologists. VEGETABLE REMAINS are present in all the groups, and frequently in such profusion as to form seams and beds of lignite, jet, and coal. The Equisetums still survive (*E. arenaceus*). Of Tree-ferns we have *Sphenopteris* and *Tæniopteris*. Of the great division of the Gymnosperms both sections were represented. The

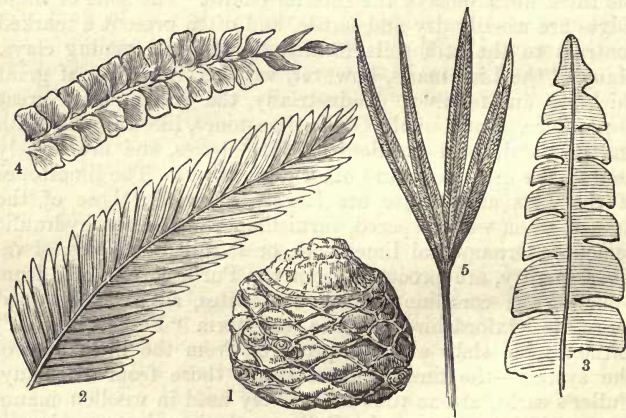


Fig. 116.—1, *Mantellia nidiformis*; 2, *Pterophyllum comptum*; 3, *Zamites intermedius*; 4, *Cyclopteris Beanii*; 5, *Glossopteris elegans*.

Cycads were most abundant and characteristic (*Cycadites*, *Zamites*, and *Mantellia*, and many other genera with fern-like leaves—*Pterophyllum* and *Plerozamites*). The Conifers

were less abundant, and were represented by forms similar to the recent *Araucaria*, Yew, and Cypress (*Araucarites*, *Pinites*, *Thuyites*). Even Monocotyledonous forms allied to the modern screw-palm, or *Pandanus*, were in existence, but are rarely represented by more than their curious cones (*Podocarya Bucklandi*). One of the most remarkable facts connected with the vegetation of the period, is the occurrence of dark loam-like strata (locally known as the "dirt-beds" of Portland), which must have formed the soils on which grew the Cycads and other Oolitic plants, though now interstratified with limestones, sandstones, and shales. "At the distance of two feet we find an entire change from marine strata to strata

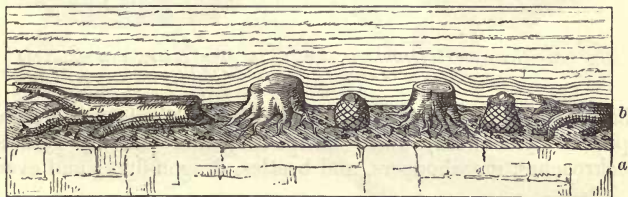


Fig. 117.—Dirt-bed (ancient soil), Portland.

once supporting terrestrial plants; and should any doubt arise respecting the original place and position of these plants, there is over the lower dirt-bed a stratum of fresh-water limestone, and upon this a thick dirt-bed, containing not only Cycadeæ, but stumps of trees from three to seven feet in height, in an erect position, with their roots extending beneath them. Stems of trees are found prostrate upon the same stratum, some of them from twenty to twenty-five feet in length, and from one to two feet in diameter."

253. With respect to the ANIMAL REMAINS, we have representatives of the majority of existing groups, with the exception of the higher mammalia. There are Foraminifera and Sponges. The Actinozoa or Corals are remarkably abundant. The Rugose or four-rayed Corals of the Palæozoic are absent, but the six-rayed Corals crowd the old Jurassic reefs (*Thecosmilia*, *Montlivaltia*, *Isastræa*). Of the Echinodermata, the chief were Crinoids (*Apiocrinus* and *Pentacrinus*), Star-fishes (*Asterias*, *Ophiura*), and Sea-urchins (*Echinus*, *Clypeus*, and the beautiful *Cidaris*). The *Brachiopoda* still show a few characteristic forms (*Rhynchonella* and *Terebratula*), but the Palæozoic groups of the *Spirifers* and *Leptænas* die

out altogether in the Oolite. The Articulata show no more representatives of the ancient types, but we have in their place Crustacea like the minute bivalved *Cyprides*, the lobster-

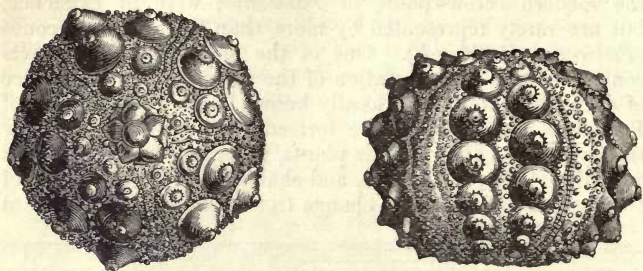


Fig. 118.—*Hemicidaris crenularis*, showing the great tubercles on which the spines were supported. Middle Oolites.

like *Eryon*, &c. Of the air-breathing Articulata we have spiders (Arachnida) and Centipedes; and among Insects cockroaches, grasshoppers, and beetles, dragon-flies; and even

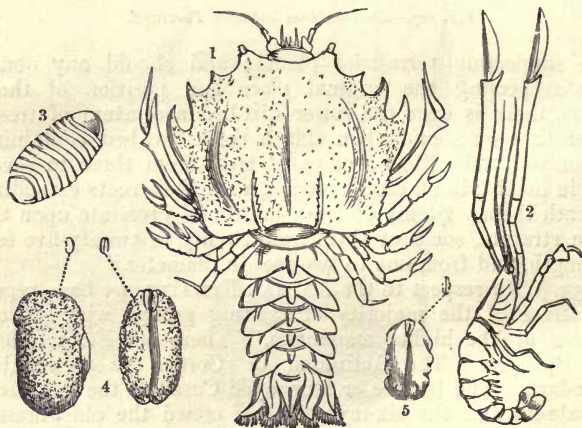


Fig. 119.—1, *Eryon arctiformis*; 2, *Mecocheirus Pearcei*; 3, *Archæoniscus Brodiei*; 4, 5, *Cyprides*—natural size, and magnified.

the wing of a butterfly (*Palæontina oolitica*) has been obtained from the Stonesfield Slates. The Mollusca are, however, by far the most important and characteristic of the Invertebrate

forms. Among the Lamellibranchiata we find Oysters (*Ostrea*, *Gryphæa*, and *Exogyra*) and their relatives (*Pecten*, *Lima*, *Spondylus*; Mussels (*Modiola*), the cockle-like *Cardium* and

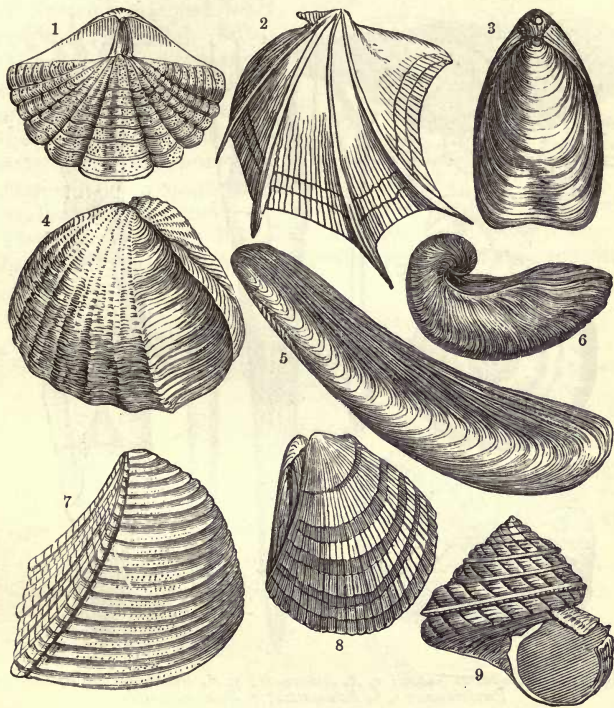


Fig. 120.—1, *Spirifer Walcotii*; 2, *Avicula cygnipes*; 3, *Terebratulina digona*; 4, *Pholadomya Murchisoni*; 5, *Modiola Fittoni*; 6, *Gryphæa incurva*; 7, *Trigonina costata*; 8, *Lima gigantea*; 9, *Pleurotomaria ornata*.

*Trigonina*. Among the Gasteropoda the chief forms are *Nerinea*, and the ancient *Pleurotomaria*; and we find here for the first time examples of the Whelks (*Buccinum*) and Spindle-shells (*Fusus*). Lastly we have the class of the Cephalopoda, which seems to have attained its culmination in Jurassic times. The great group of the Ammonites claims some hundreds of Jurassic species, and the system has been divided by their means into a large number of *Zones*, each

characterised by its own species of Ammonite. They belong to the Tetrabranchiate (four-armed) section of the Cephalopoda, a group which also includes the living *Nautilus*, the *Goniatites*

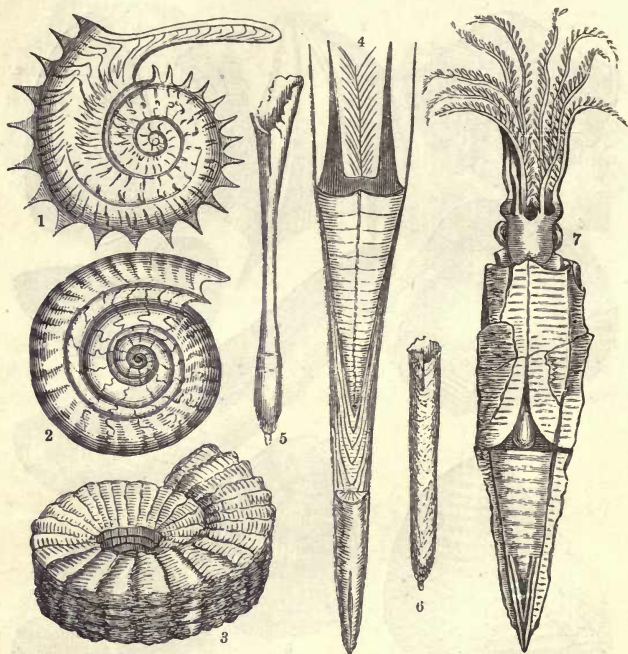


Fig. 121.—*Ammonites Jason*; 2, *A. communis*; 3, *A. Bucklandi*; 4, *Belemnites Puzosianus*; 5, 6, *Belemnites*; 7, *Belemnoteuthis*.

of the Deuterozoic, and the *Ceratites* of the Triassic rocks. From these older forms the Ammonites are separated by the remarkably complex fashion in which the edges of the septa (or partitions between the air-chambers) are folded. To the Dibranchiate (two-armed) division of the Cephalopoda belong the abundant Jurassic cuttle-fishes or *Belemnites* (Gr. *belemnos*, a dart), so named from the horny or calcareous internal structure which supports their soft tissues. Even the “ink-bag,” containing the unaltered sepia of these ancient creatures, is sometimes found in the Jurassic clays.

254. Of the higher or *Vertebrate* forms of animal life, we

have examples of placoid and ganoid fishes, of abundant saurian reptiles, of birds, and a few species of marsupial mammals. The Ganoids (*Tetragonolepis*) are here homocercal. The Placoids are represented mainly by their pointed teeth (*Hybodus*), or by teeth adapted for crushing (*Acrodus*). But the giants of the Jurassic seas were the extraordinary Reptilia. Of these, there were four distinct orders, *Ichthyosauria*, *Plesiosauria* (gigantic sea-lizards), *Deinosauria* (carnivorous land-lizards), and *Pterosauria* (flying lizards). The *Ichthyosaurus* (*ichthys*, a fish, and *saurus*, a lizard), somewhat resembled the crocodiles,



Fig. 122.—Tooth of *Acrodus nobilis*. Lias.



Fig. 123.—*Ichthyosaurus communis*.

but was furnished with paddles or flippers instead of limbs. Many species have been discovered, varying in length from four to forty feet. The *Plesiosaurus* (*plesios*, more—so called

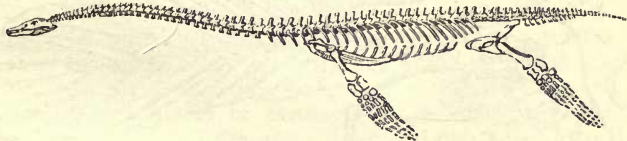


Fig. 124.—*Plesiosaurus dolichodeirus*.

from its greater resemblance to the modern lizards) was distinguished by its enormous length of neck, smaller head, and shorter body and tail. The *Pterodactyle* (*pteron*, a wing, and *daktylos*, a finger) was so called from being furnished with membranous expansions joining the extended terminal digit and the body, so that it was capable, like bats, of mounting in the air. Of the *Deinosauria*, the chief Jurassic genera are *Megalosaurus* and *Cetiosaurus*. They were land animals, and were of gigantic size, from thirty to fifty feet in length. In some species the hind-limbs were much stronger than the fore-

limbs, so that they probably walked, at least occasionally, on their hind-feet, and thus must have borne a striking likeness to gigantic birds. In various details of their organisation,

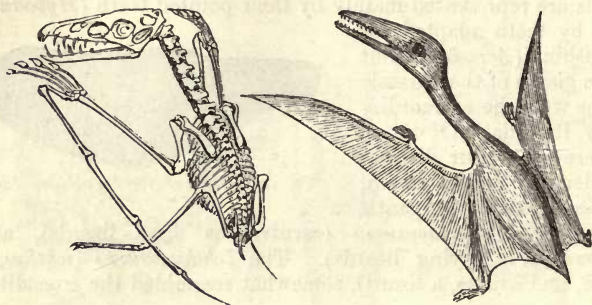


Fig. 125.—*Pterodactylus crassirostris*.

also, they are, indeed, distinctly related to the Birds. True birds, however, were at this period in existence. The oldest example yet detected is the *Archæopteryx macrura*, from the

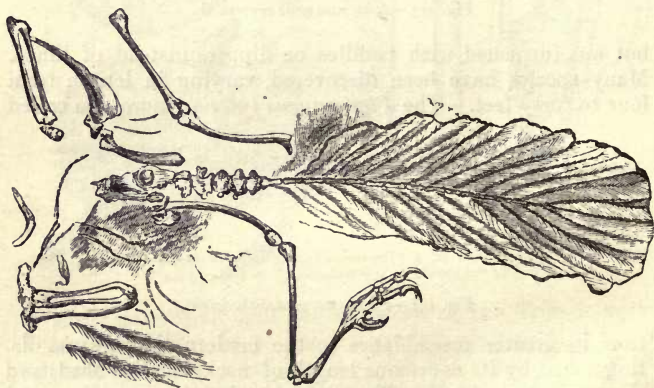


Fig. 126.—*Archæopteryx macrura*; Tail and detached bones.

Jurassic of Solenhofen, South Germany. This creature was about the size of a modern pigeon. It was furnished with a long narrow tail, of twenty vertebræ, each of which carried a pair of strong feathers. Its jaws were furnished with conical teeth, and in many of its structural characters it approached

the Deinosaurian reptiles. The Jurassic Mammalia were all apparently marsupial, allied to the kangaroos and opossums. They are represented usually by lower jawbones and teeth : the

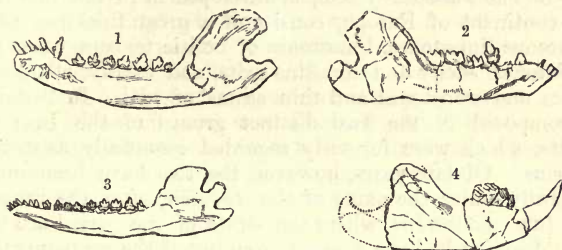


Fig. 127.—Oolitic Mammals, natural size : 1, *Lower Jaw and Teeth of Phascolotherium Bucklandi*; 2, of *Triconodon*; 3, of *Amphitherium*; 4, of *Plagiaulax*.

chief genera being the *Amphitherium* and *Phascolotherium* of the Stonesfield Slates, and the *Plagiaulax* of the Purbeck beds.

255. Respecting the conditions of the British and west European areas during the deposition of the Jurassic strata, we have already stated that everything reminds us of a genial and equable climate. "The close approximation of the *Amphitherium* and *Phascolotherium*," says Professor Owen, "to marsupial genera now confined to New South Wales and Van Diemen's Land, leads us to reflect upon the interesting correspondence between other organic remains of the British Oolite and other existing forms now confined to the Australian continent and adjoining seas. Here, for example, swims the *Cestracion*, which has given the key to the nature of the palates from our Oolite, now recognised as the *teeth* of congeneric gigantic forms of cartilaginous fishes. Not only *Trigonia*, but living *Terebratulæ* exist, and the latter abundantly, in the Australian seas, yielding food to the *Cestracions*, as their extinct analogues doubtless did to the allied cartilaginous fishes called *Acrodi* and *Psammodi*, &c. *Araucariæ* and cycadaceous plants likewise flourish on the Australian continent, where marsupial quadrupeds abound, and thus appear to complete a picture of an ancient condition of the earth's surface, which has been superseded in our hemisphere by other strata, and a higher type of mammalian organisation."

## RECAPITULATION.

256. The Jurassic system, as developed in Britain and upon the continent of Europe, consist of a great thickness of argillaceous limestones, limestones of oolitic texture, calcareous sandstones, shelly and coralline grits, and locally, of pyritous shales and ironstones and thin seams of coal. In Britain it is composed of the two distinct groups of the Lias and Oolite, which were formerly regarded essentially as distinct systems. Of late years, however, the two have been united generally under the name of the *Jurassic*, after the range of the Jura mountains, where the strata of the period are typically developed. The general grouping of the component formations is in principle the same, among both British and Continental geologists; but the *names* given to the various sections themselves are different in different countries. The following table gives a brief outline of the nomenclatures adopted in Britain, France, and north-west Germany respectively:—

ENGLAND.	FRANCE.	N.-W. GERMANY.
OOLITE FORMATIONS.		
3. <i>Upper or Portland Oolites</i> — Purbeck Beds. Portland Beds. Kimmeridge Clay.	Purbeckien. Portlandien. Kimmeridgien.	} <i>Upper or White Jura.</i> (Malm.)
2. <i>Middle or Oxford Oolite</i> — Coral Rag and Calcareous Grit.  Oxford Clay and Kelloway Rock.	Corallien. { Oxfordien (in- cluding Ar- govien and Cal- lovien).	
1. <i>Lower or Bath Oolites</i> — (a) Upper or Great Oolite Group— Cornbrash and (Bradford Clay). Great Oolite Limestone and (Stonesfield Slates).	{ Bathonien or Grand Oolithe.	} <i>Middle or Brown Jura.</i> (Dogger.)
(b) Lower or Inferior Oolite Group— Fuller's Earth. Inferior Oolite Limestones. Basement Beds.	{ Bajoicien (from Bayeux) or Oolithe Infe- reure.	
LIASSIC FORMATIONS.		
3. Upper Lias Clays.	Toarcien (Tours).	} <i>Lower or Black Jura.</i> (Lias.)
2. Middle Lias or Marlstone.	Liassien.	
1. Lower Lias Clays and Limestones.	{ Sinémurien and Hettangien.	

257. The system is mainly composed of argillaceous limestones, limestones of oolitic texture, calcareous sandstones, shelly and coralline grits, clays and pyritous shales, with layers of coal, jet, and ironstone. All the members are well developed in England, France, Switzerland, and Germany; and the system is present in Scotland, in Hindustan, and in North America. As deposits, the lias and oolitic strata of France and south-west England are eminently marine; while many of those of north-east England and Scotland are as evidently of estuarine or fresh-water formation. Broad seas and estuaries of varying depth were apparently the great receptacles in which the entire suite of strata were deposited—deep but muddy waters for the finely laminated lias and oolitic clays; shallower but clearer waters for the shelly grits and coralline reefs of the oolite, and broad estuaries and deltas for the shales and ironstones of Yorkshire and Scotland; while over the whole area there must have been repeated elevations and depressions of sea-floor, as well as of terrestrial surface. The climate must have been warm and equable, and all the conditions, terrestrial and marine, such as to result in a marvellous richness and variety of animal and of vegetable life.

258. With the exception of the higher Mammalia, almost every existing order of animals is represented in the fauna of the Jurassic; but the genera are all Mesozoic, and most of them died out at the close of the Cretaceous era. The vegetation of the system is also extremely varied, but the highest groups appear to be conifers and palms—no example of a true exogenous timber-tree having yet been detected. Of its numerous vegetable fossils, the most characteristic are the Cycads, of which the stem, fruits, and leaves are found in abundance. Corals, Echinoderms, and Brachiopoda are abundant, but the genera of the last-named are dying out. Mollusca are in great abundance, Lamellibranchs, Gasteropods, and especially the Cephalopoda of the families of the *Ammonites* and *Belemnites*. Of Vertebrata we have Fishes, Amphibia, Reptiles, and the marsupial Mammalia. Chief of these were the extraordinary Reptilia belonging to the great groups of the *Ichthyosauria*, *Plesiosauria*, *Pterosauria*, and *Deinosauria*, whose marvellous forms and variety have suggested for the Jurassic the not inappropriate title of the “Age of Reptiles.” Still higher in the scale of being than these are the remains of a bird fitted for flight (*Archæopteryx*); and the curious marsupial mammals (*Amphitherium*, *Plagiaulax*, and *Stereog-*

*nathus*). Building-stone, paving-stone, limestone, alum, coal, ironstone, jet, and lithographic slabs are the principal economic products of the system.

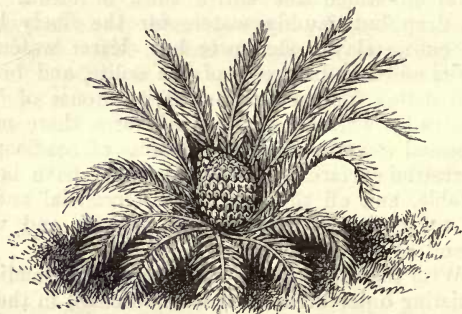


Fig. 128.—*Zamia spiralis*, a living Cycad, Australia.

## CHAPTER XX.

## THE CRETACEOUS SYSTEM.

259. IMMEDIATELY above the Jurassic formations of England occur a set of well-defined estuarine deposits, marine sands, dark marls, clays, and thick beds of pure chalk. These strata constitute the *Cretaceous system*—the chalk (Lat. *creta*) formation being the most prominent and remarkable feature in the series. The Cretaceous is in many respects one of the most remarkable rock-systems in the British Islands, and has consequently long attracted the researches of geologists. As the uppermost member of the younger Secondaries, it closes the record of Mesozoic life; and of the innumerable species which composed the flora and fauna of the Secondary epochs, comparatively few have been detected in Tertiary or Post-Tertiary strata. Lithologically, it is composed of cretaceous, argillaceous, and arenaceous rocks—the first predominating in the Upper, and the two last in the Lower portion of the system. Like all other systems, the Cretaceous is characterised by local differences—the chalk itself being sometimes a soft incoherent carbonate of lime, at others indurated; at some a yellowish limestone, and at others metamorphosed into a crystalline marble; while in some regions the chalk proper is poorly represented, and the system is composed mainly of arenaceous and clayey beds, enclosing workable seams of coal. As occurring in England, the component members are usually grouped as follows:—

## UPPER CRETACEOUS OR CHALK FORMATIONS.

*Upper Chalk*.—Soft white chalk, containing numerous flint nodules, more or less arranged in layers. Fossils—*Belemnitella mucronata*, *Marsupites ornatus*.

*Lower Chalk*.—Harder and less white than the upper, and generally with fewer flints. *Holaster planus*, *H. subglobosus*.

*Chalk Marl, &c.*—A greyish or yellowish marly chalk.

*Upper Greensand*.—Beds of siliceous sand, with grains of glauconite (greensands). *Pecten asper*, *Ammonites inflatus*.

*Gault*.—A provincial name for a bluish tenacious clay. *Ammonites cristatus*.

#### LOWER CHALK OR NEOCOMIAN FORMATIONS.

*Lower Greensand*.—Yellow, grey, and green sands, with bands of limestone and ironstone. *Ammonites Deshayesii*, *Perna Mulleti*, *Ancylloceras gigas*.

*Wealden*.—A thick series of fluviatile deposits, separable into two main sections—Upper or *Weald Clay*, and Lower or Hastings Sand group. *Iguanodon Mantelli*, *Unio Valdensis*.

In Yorkshire we have a marine representative of the Lower Cretaceous in the *Speeton Clays*, the upper zones of which contain *Perna Mulleti*; the middle, *Ancylloceras gigas* and *Pecten cinctus*; and the lower, *Ammonites speetonensis*, *A. noricus*, &c. The *Upper Cretaceous* or Chalk Series is wholly of marine origin, and represents a period when Britain and much of western Europe was depressed to a great depth below the sea-level. The *Lower Cretaceous* of south-west England has its inferior division formed of an enormous thickness of fluviatile deposits—about 2000 feet in thickness—known as the Wealden formation. It is so named from the “Weald” or woodland of Kent or Sussex, where this formation prevails. It consists chiefly of clays and shales, sandstones, and shelly limestones, all of which indicate an estuarine or brackish-water origin. Thus partings of lignite and bituminous shale are not unfrequent among the clayey strata; and in some districts, layers and nodules of ironstone are so abundant, as to have been of great economic importance during the existence of the forest-growths of Sussex. Its strata occur not only in England, but are continued into the north of France, and must originally have occupied a region 320 miles long, and 20,000 square miles in area. It seems to occupy the site of an ancient Cretaceous estuary, whose waters occasionally bore down the spoils of land plants and land animals to be entombed along with those of aquatic origin. By some, however, it is believed to be wholly of lacustrine origin.

260. The preceding synopsis affords a general outline of the composition and succession of the Cretaceous system as developed in south-west England; but considerable local differences occur, both in thickness and lithological composi-

tion. The Wealden alone of all its members rests conformably upon the Jurassic rocks below. All the remaining members of the system overlap each other towards the north-west, so that the Upper Greensand rests upon the Triassic in Devon, and the Upper Cretaceous rests unconformably upon all the older formations in north Ireland and west Scotland, the lower division being wholly absent. There were also local upheavals and depressions within the limits of the typical region itself, giving rise to local erosion and unconformity. Such an unconformity is marked by the so-called Cambridge Greensand, a glauconitic marl containing phosphatic nodules, largely worked for manure. It occurs at the base of the Chalk Marl, and rests unconformably upon the Gault below. Another remarkable bed about the same, or a slightly lower horizon (Gault), is the ferruginous *Red Chalk*, seen in the cliffs at Hunstanton. In Yorkshire the fluviatile Wealden series is represented, at least in part, by a marine formation known as the *Speeton Clay*. When we come to compare the Continental strata with those of England, still wider differences prevail. The soft white chalk of the British area is represented in the Mediterranean basin by thick limestones, crowded with the curious fossil *Hippurites*. At the top of the Cretaceous series of Britain, some of the strata belonging to the system are wanting. The missing zones are found in Europe, where they are known as the Maestricht Chalk, or *Danien*, from their great development at Maestricht, and in Denmark (Faxøe), in both of which areas (as well as near Paris) they consist of yellow limestones or chalk, containing the characteristic fossil *Nautilus Danicus*. In North America the rocks which are charged with Cretaceous fossils are often mere sands and clays, sometimes even shingly, and containing in Colorado and British Columbia workable seams of lignite and coal.

261. Regarding the geographical distribution of the Cretaceous rocks, we find the White Chalk of England fully developed in the south-west half of the country, its western outcrop forming a range of heights stretching from the English Channel near Purbeck, through the Chiltern Hills, West Norfolk, Lincolnshire, and through south-east Yorkshire to the sea at Flamborough Head. A range of similar heights, the North and South Downs, encloses the inner anticlinal of the Weald. The same Upper Cretaceous formation occurs in Antrim, below the great sheets of basalt of that county, and also in Mull and Morven on the W. coast of Scot-

land. It can be traced eastwards across Europe to the base of the Urals. South of the great mountain ridges of the Alps and central France, Cretaceous rocks occur in force in Gascony, in the Pyrenees, the Apennines, and the Balkans. Crossing into Asia, they can be followed through Syria and Persia into India. In North America they sweep round the south-western flanks of the Alleghanies, across the basin of the Mississippi into Texas. Thence they can be followed in great thickness and over wide geographical areas in Colorado, in British Columbia, and thence to the mouth of the Mackenzie River; they occur also even in northern Greenland.

262. No igneous rocks are found associated with the chalk of England, but in the north of Ireland the strata are indurated, disrupted, and overlaid by sheets of basalt, so remarkably displayed at the Giant's Causeway. In the Pyrenees and Alps the system partakes more or less of all those upheavals by mighty crust-movements which are so characteristic of these lofty ranges; and in Greece and the upper Mediterranean several of the saccharoid and veined marbles are regarded as metamorphosed limestones of the Cretaceous epoch. In England the physical aspect of chalk districts is readily distinguished by the rounded outlines of their hills and valleys, as typically exhibited in the "wolds" and "downs" of Kent and Sussex. These downs are described as "covered with a sweet short herbage, forming excellent sheep-pasture, generally bare of trees, and singularly dry even in the valleys, which for miles wind and receive complicated branches, all descending in a regular slope, yet are frequently left entirely dry; and, what is more singular, contain no channel, and but little other circumstantial proof of the action of water, by which they were certainly excavated." Industrially, the chief products of the system in Britain are chalk and flint. Chalk, as an almost pure carbonate of lime, is calcined like ordinary limestones, and employed by the bricklayer, plasterer, cement-maker, and farmer; and, levigated, it furnishes the well-known "whiting" of the painter. Flint, calcined and ground, is used in the manufacture of china, porcelain, and flint-glass; and before the invention of percussion-caps, was in universal use for gun-flints. In the south of England flints are employed as road material; and the larger nodules are sometimes taken for the building of walls and fences. Beds of fuller's earth occur in the lower series; and some of the indurated strata, like the "Kentish rag" and Chalk-marl of Cambridgeshire, furnish local supplies of building-stone.

From the Greensand of Cambridge are obtained those phosphatic nodules and concretions now so largely used in the manufacture of artificial manure, on account of their containing a large percentage of phosphate of lime. More recently, several of the workable coal-seams of Vancouver Island and British North America, as well as of Colorado, have been ascertained to belong to the Cretaceous epoch, or to the period embracing the Upper Cretaceous and Lower Tertiary.

263. As might be expected, Fossil PLANTS are rare in the British Cretaceous rocks, except in the fluviatile deposit of the Wealden, where abundant examples of Conifers, Cycads, and Ferns have been obtained, but few or no leaves or fruits of *Angiosperms*. That this highest and most important

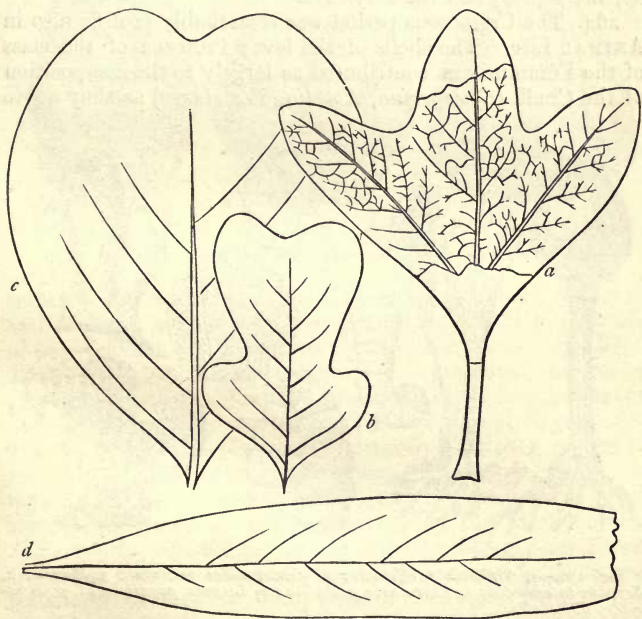


Fig. 129.—Cretaceous Angiosperms: *a*, *Sassafraz Cretaceum*; *b*, *Liriodendron Meekii*; *c*, *Leguminosites Marcouanus*; *d*, *Salix Meekii*. (After Dana.)

division of Plants was, however, in existence in Cretaceous times, is abundantly demonstrated by the extraordinary number of examples obtained from the Upper Cretaceous rocks of

other countries. In the Cretaceous rocks of Aix-la-Chapelle, plants occur in abundance, and all the great plant divisions are represented in pretty much the same proportions as obtain among the plants of the present day. There are Tree-ferns, Conifers, Cycads, and a few Monocotyledons; but the majority belong to the highest division, or Dicotyledonous Angiosperms. We have the *Oak*, the *Fig*, and *Walnut*; and abundant *Proteaceæ*, the last belonging to a group of plants now extinct except in Australia. In the Cretaceous rocks of Colorado, at least 100 species of Angiosperms have been obtained, most of them allied to the American plants of the present time. Even in the Arctic district of Greenland (Noursoak) the Upper Cretaceous rocks yield examples of the *fig*, the *poplar*, and the *magnolia*.

264. The Cretaceous period was remarkably prolific also in ANIMAL Life. The shells of the lowly Protozoa of the class of the Foraminifera contributed as largely to the composition of the Chalk (*Globigerina*, *Rotalia*, *Textularia*) as they do to

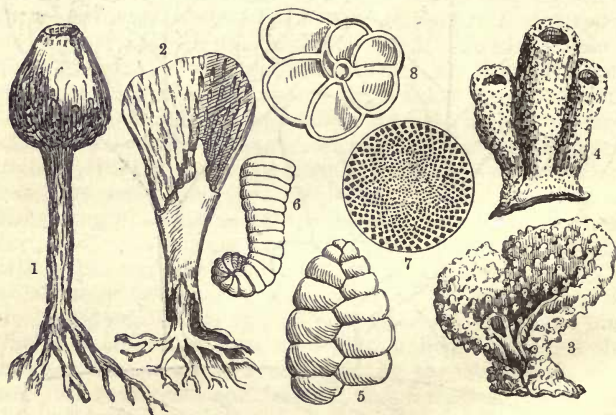


Fig. 130.—1, *Siphonia pyriformis*; 2, *Ventriculites radiatus*; 3, *Manon*; 4, *Scyphia intermedia*; 5, *Textularia globulosa*; 6, *Lituola nautiloidea*; 7, *Orbitoides*; 8, *Rotalia*.

the modern deep-sea oozes. The Spongida were extremely abundant (*Ventriculites* and *Siphonia*). The majority of these were siliceous, and their abundant spicules contributed largely to the masses of solid flint which characterise the English Chalk. Corals are few in number in the British deposits,

and belong to the same great groups as modern forms. Among the Echinoderms, one of the most curious was the *Marsupites* or Tortoise-Encrinite, a link between the free and the stalked

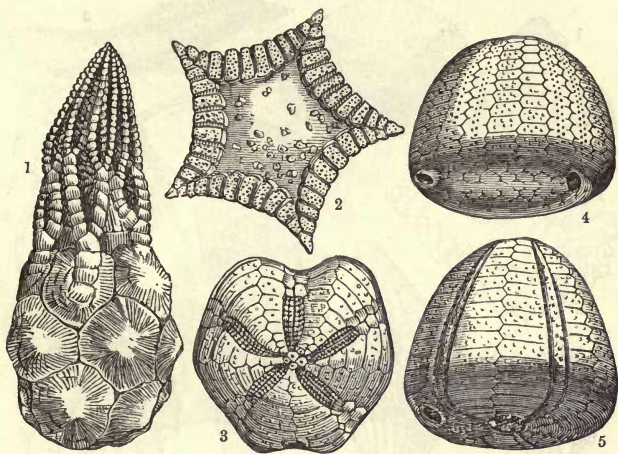


Fig. 131.—1, *Marsupites Milleri*; 2, *Goniaster Mantelli*; 3, *Hemipneustes radiatus*; 4, *Ananchytes ovata*; 5, *Galerites albogalerus*.

forms. Sea-urchins (Echinoids) were abundant (*Galerites* and *Micraster*). To the Crustacea belong the little *Cyprides* of the Wealden, and numerous forms of *Barnacles* (*Lepadidæ*). The Polyzoa or Sea-mats were well represented, several of great size (*Eschara*); but the Brachiopoda are few in number, and claimed mainly the genera *Terebratula* and *Rhynchonella*. The Lamellibranchs (Bivalves), however, were even more prevalent and varied than in the earlier Jurassic—especially the mussels (*Unio*), oysters (*Gryphæa*), and *Trigonias*. The pearl-mussels (*Aviculidæ*) were represented by the family of the *Inoceramidæ*, including among others the genera *Perna*, *Gervillia*, and *Inoceramus*, the last being especially characteristic of Cretaceous rocks, some of the species being two or three feet in length. But the most remarkable family was that of the *Hippuritidæ*. The lower shell of *Hippurites* was in the form of a horn, sometimes more than a foot in length: more than a hundred species are known, forming massive calcareous beds in Southern Europe (Hippurite Limestone). Among the univalves or Gasteropods we find the Jurassic

genera *Nerinea* and *Pleurotomaria*, in association with *Turritella* and *Natica*; and in the highest beds (Danian) of the system, we meet for the first time with the modern genera of

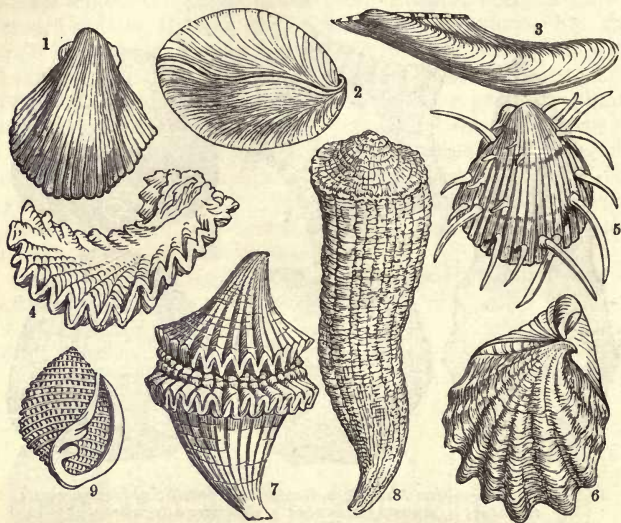


Fig. 132.—1, *Pecten quinque-costatus*; 2, *Terebratula semiglobosa*; 3, *Gervillia anceps*; 4, *Ostrea carinata*; 5, *Spondylus spinosus*; 6, *Inoceramus sulcatus*; 7, *Radiolites turbinata*; 8, *Hippurites Toucasianus*; 9, *Cinulia*.

the Volutes (*Voluta*) and the Cowries (*Cypræa*). The Cephalopodous forms, too, appear in vast profusion and in highly curious shapes as compared with those of the earlier systems. Of these the coiled-up *Ammonite*, the hook-shaped *Hamite* (*hamus*, a hook), the boat-shaped *Scaphite* (*scapha*, a skiff), the tower-like *Turritite*, and the twisted *Ancylloceras*, all belong to the family of the Ammonitidæ. The *Nautilus* still survives, and the Dibranchiate Cephalopods are represented by *Belemnites* and *Belemnitella*.

265. Coming next to the *Vertebrate* Animals, we still find Ganoids (*Lepidotus*) and Placoids (*Acrodus* and *Ptychodus*, wrinkle-tooth). Here we recognise for the first time abundant examples of the Teleostian or Bony fishes; *Beryx*, allied to the modern Perch, and *Osmeros*, belonging to the Salmon tribe. Few or no Amphibia occur in British Cretaceous rocks, but Reptiles are abundant—the Jurassic orders being

still represented by *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus*, the last of which attains gigantic dimensions; some of the Cretaceous forms having had a "spread of wing of

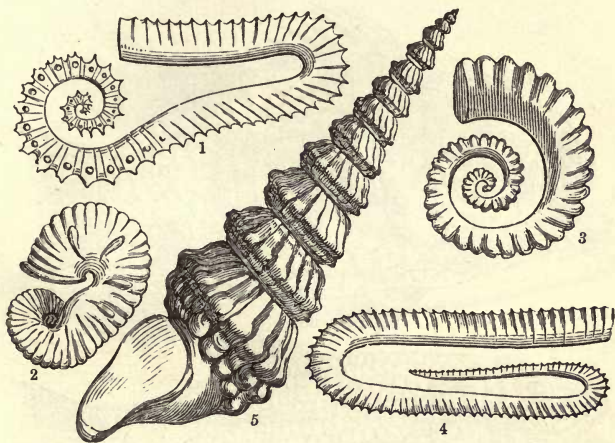


Fig. 133.—1, *Ancyloceras Matheronianus*; 2, *Scaphites æqualis*; 3, *Crioceras Duvalii*; 4, *Hamites attenuatus*; 5, *Turritiles catenatus*.

from 20 to 25 feet." The *Deinosauria* show several fresh types. Most remarkable of these was the *Iguanodon* (*Mantellia*) of the Wealdens, a herbivorous reptile measuring from 30 to 50 feet in length, with weak fore-limbs, but strong and massive hind-limbs, and three-toed hind-feet, upon which it appears to have usually walked, somewhat after the manner of a bird. A group of Reptiles confined solely to the Cretaceous rocks was the Mosasauridæ, typified by *Mosasaurus* (Lizard of the Meuse) of the Maestricht Chalk, a long snake-like animal, with pointed teeth, and furnished with swimming-paddles, and a long and powerful tail. The *Mosasaurus princeps* of the Cretaceous of North America must have been at least 75 or 80 feet in length. The remains of Birds are rare in Britain. Two species of *Enaliornis* occur, however, in Cambridge Greensand; but in the Cretaceous rocks of America the researches of Professor Marsh have made us acquainted with some of the most wonderful of all the extinct forms of bird-life. They belong to the order of the *Odontornithes* (Toothed birds, their jaws being armed with sharp-pointed teeth like most reptiles)—true birds, but showing reptilian

affinities, and closely related to Deinosauria and Pterosauria. Of these, *Ichthyornis* (fish-bird) was about the size of a common pigeon. *Hesperornis* (bird of the west), about six feet

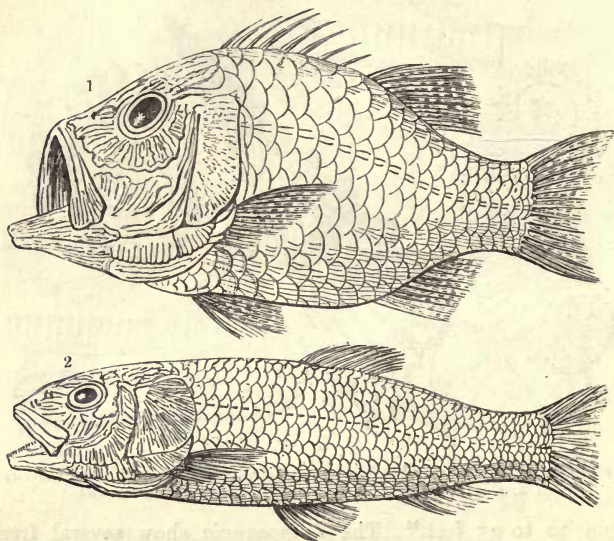


Fig. 134.—1, *Beryx Lewesiensis*; 2, *Osmeroides Mantelli*. (Mantell.)

in length, was apparently destitute of organs of flight, but was furnished with a long, flat, beaver-like tail.

266. Respecting the conditions of the waters in which the Chalk, so unlike ordinary limestones, was deposited, and within whose mass flints were subsequently aggregated, it must be acknowledged that it bears a striking resemblance to the calcareous deep-sea oozes now being laid down on the ocean floor. Like the Chalk, these are mainly composed of the shields of Foraminifera, many of which are identical in genera with those whose shields make up so large a percentage of the Chalk. In other words, the Chalk is certainly an old foraminiferal mud or ooze; but the apparently limited area in which it was deposited appears to preclude the view that the waters in which it was laid down were as deep or as broad as those in which the modern oozes are being formed. The abundance of enclosed sponges, sea-urchins, star-fishes, and fragments of marine organisms, also speaks strongly in

favour of the same view, and compels us to seek for the enclosed layers of flint an origin similar to that of nodules of ironstone and chert.

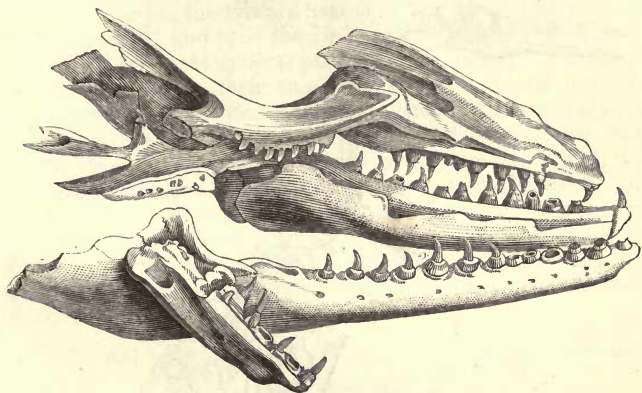


Fig. 135.—Skull of *Mosasaurus Camperi*, much reduced. *Maestricht Chalk.*

Flints are composed almost entirely of pure silica, and usually aggregated round some nucleus of sponge, shell, mass of sponge spicules, or other matter of organic origin. There is little difficulty in conceiving the silica of siliceous organisms, like the abundant siliceous sponges of the Chalk, as having been more or less dissolved, perhaps by the aid of decaying organic matter, and subsequently redeposited, and segregated in layers and nodules as we now behold it. The deep-water mode of origin of the Chalk strata is further confirmed by the nature of the Greensand, which, according to Dr Carpenter, is coloured green by ferrous silicate which has been infiltrated into the shields of Foraminifera, the shelly coverings having since been dissolved away.

#### RECAPITULATION.

267. The Cretaceous system—so called from the Chalk-beds which form its most notable feature—is the last or uppermost of the Secondary formations. All its types of life are strictly Mesozoic, and of the numerous species found in the Trias, Oolite, and Chalk, comparatively few have been detected in Tertiary strata. It is an error, however, to sup-

pose that there is any universal sharp line of demarcation, either physical or biological, between Palæozoic and Mesozoic, or Mesozoic and Cainozoic. As one Rock-system runs into

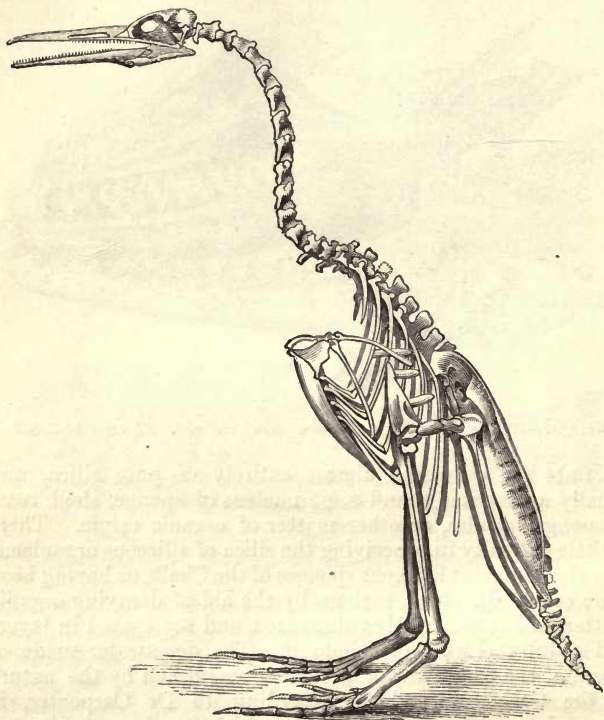


Fig. 156.—*Skeleton of Hesperornis regalis, restored (after Marsh). About one-tenth of the natural size.*

another system in one area or another, so does one great Life-period pass into another period, and it is only when viewed as a whole that we can note the differences that exist between their respective plants and animals. Our "Groups," and "Systems," and "Periods" are mere provisional expedients; useful as such, but leading to error when invested with any other significance. In Britain the Cretaceous rocks are classified almost wholly by lithological characters, and these original divisions retain to a large extent their primary

value ; but when they are traced from the typical areas into other regions where the conditions were different, they are no longer recognisable. But while the physical gradation was frequently different in Britain from that of some parts of western Europe, the onward march of life was, broadly speaking, the same ; and thus the British and Continental deposits can be brought into general parallelism by means of the fossils which characterise their successive *zones* of animal life. In France the classification of the Cretaceous rocks usually followed is that of D'Orbigny, which has the advantage, that while it admits of fairly satisfactory comparison with the British lithological scheme, it gives a better idea of the palæontological succession ; and it is therefore coming largely into use even among British geologists. In the following outline the English and French schemes of classification are placed side by side, for the purposes of reference and comparison :—

## ENGLISH FORMATIONS.

## FRENCH SYSTÈMES.

*Upper Cretaceous.*

Danian (wanting in England),	. . . . .	Danien.
Upper Chalk (with Flints),	. . . . .	Sénonien.
Lower Chalk (without Flints),	. . . . .	Turonien.
Superior Division,	. . . . . }	
Inferior Division,	. . . . . }	Cénomanién.
Chalk Marl and Chloritic Marl,	. . . . . }	
Upper Greensand,	. . . . . }	Albien.
Gault,	. . . . .	

*Lower Cretaceous.*

Lower Greensand ( <i>marine</i> ) (Atherfield, {	. . . . .	Aptien.
Hythe, and Folkestone beds, &c.), {	. . . . .	Rhodanien.
Wealden (including the Weald Clay and {	. . . . .	Urgonien.
Hastings Sands and Clays) ( <i>fluvatile</i> ), {	. . . . .	Néocomien.

The Yorkshire equivalents of the Lower Cretaceous are all marine (*Speeton Clay*), and are generally referred to under the title of *Neocomian*, a name frequently employed to designate the whole of the Lower Cretaceous, but originally applied by D'Orbigny to its lowest member only (*Neocomien*), from its typical development near Neufchatel (Switzerland), the ancient Neocomum. These various members, both in point of composition and fossil remains, bear evidence of deposit—the Wealden in a great lake or estuary, the Chalk in seas of great depth and wide area, and of a land climate suitable for

the growth of Cycads and Proteaceæ on land, and of gigantic saurians and turtles in the waters. And yet, as chalk is now being formed along the temperate zones of the Atlantic seabed, so may the chalk proper have been similarly aggregated, though in narrower and perhaps shallower waters; and as icebergs now drop their boulders among the Atlantic ooze, so we may account for the occasional presence of boulders of igneous and metamorphic rocks among the white chalk and upper greensand of England. Palæontologically, the remains of the Cretaceous are eminently marine, and comprise numerous species of Sponges, Foraminifera, Star-fish, Sea-urchins, Mollusca, Crustacea, Fishes, Reptiles, and toothed Birds. The chief, and indeed the only, industrial products of the system in England are chalk, flint, phosphatic nodules, and some inferior building-stones; but in some foreign localities lignite, coal, and ironstone and other metallic ores, occur in available abundance.

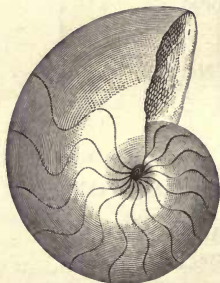


Fig. 137.—*Nautilus Danicus*.

## SECTION V.—CAINOZOIC PERIOD.

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### CHAPTER XXI.

#### THE TERTIARY SYSTEM.

EMBRACING THE EOCENE, OLIGOCENE, MIOCENE, PLIOCENE  
GROUPS.

268. THE earlier geologists, in dividing the stratified crust into Primary, Secondary, and Tertiary formations, regarded as Tertiary all that occurs above the Chalk. The term is still retained, but the progress of discovery has rendered it necessary to restrict and modify its meaning. Even yet the limits of the system may be said to be unsettled—some embracing under the term all that lies between the Chalk and Boulder-drift, others including the Drift and every other accumulation in which no trace of man or his works can be detected. Palæontologically speaking, much might be said in favour of both views; but the difficulty of unravelling the relations of many clays, sands, and gravels, makes it safer to adopt in the meantime a somewhat provisional arrangement. We shall therefore treat as TERTIARY all that occurs above the Chalk to the commencement of the Drift, and as POST-TERTIARY or QUATERNARY every accumulation which appears to have been formed since that period. Adopting this arrangement, we have the following intelligible divisions:—

POST-TERTIARY or	{ RECENT and Superficial accumulations. PLEISTOCENE, or Glacial formations.
QUATERNARY.	

TERTIARY.	UPPER.	PLIOCENE.....	Craggs and Forest Bed of Norfolk and Suffolk.
		MIOCENE.....	Absent from Britain.
	LOWER.	OLIGOCENE....	Headon and Hempstead Series of the Isle of Wight.
		EOCENE.....	Bagshot Beds, London Clay, and the Lower London Tertiaries.

The organic types of the Tertiary system as thus restricted are all *Cainozoic*—that is, are all more or less allied to, or even identical with, many existing genera. As at the close of the *Palæozoic* cycle, graptolite, trilobite, eurypterite; cephalaspis, pterichthys, coccosteus, megalichthys, palæoniscus; sigillaria, lepidodendron, and other forms of ancient life had passed away—so, at the close of the *Mesozoic*, the ichthyosaurus, plesiosaurus, pterodactyle, hybodus, ammonite, disappeared, and their places were taken by other and more recent-like forms. We now in the *Cainozoic* find among vegetables evidence of true exogenous timber-trees (that is, trees which increase by *external* layers of growth, like the oak and beech); a large percentage of the corals and molluscs are identical with those of existing seas; the reptiles are carapaced turtles, tortoises, and crocodiles; the fishes are chiefly teleostian, with equally-lobed tails; birds of some existing families occur; and examples of mammalia of all orders up to the highest, save man, have been detected. It is true that certain genera and species discovered in Tertiary strata are not to be found beyond the limits of the Pliocene division; and it is this extinction, during the Glacial period, of many peculiar forms, that warrants the separation of the Post-Tertiary from the Tertiary system. The divisions of Tertiary were founded originally by Sir Charles Lyell upon this perceptible approach to existing species—taking the fossil shells as the index. Thus, *Eocene* (Gr. *eos*, the dawn, and *kainos*, recent) implies that the strata of this group contain only a small proportion of living species, which may be regarded as indicating the dawn of existing things; *Oligocene* (*oligos*, few) implies that the number of recent genera in its fauna is still few compared with extinct forms; *Miocene* (*meion*, less), that the proportion of recent shells is less than that of extinct; *Pliocene* (*pleion*, more), that the proportion of recent shells is more or greater than that of the extinct. It is true that the shell percentage differs in different basins; but, broadly speaking, the greater the amount of extinct species, whether of shell-fish or of other animals, contained in any set of strata, the older relatively

must these strata be regarded. As the Eocene and Oligocene divisions afford evidences of having been accumulated under very different geographical and climatic conditions from those of the present day, while they contain only a very small proportion of recent forms, they are sometimes grouped together to form the *Older Tertiary* or *Palæogene*; while the Miocene and Pliocene are regarded as *Newer Tertiary* or *Neogene*. The Older Tertiary was a period of extraordinary warmth, subtropical conditions prevailing in Britain and central Europe, and temperate conditions as far as the extreme north of Greenland. The Newer Tertiary shows a gradual increase of those colder conditions which culminated at last in the intense cold of the Glacial Epoch.

269. The Tertiary rocks of Britain, northern France, and Germany, where they were first studied, consist of sheets of soft clays, of pebble beds, thin limestones, sands, and gravels. They rest upon the denuded surface of the underlying Cretaceous rocks, and often occur in isolated "basins" or depressed areas, as if deposited in local areas and patches. Their fossils, too, are totally distinct from those of the underlying Cretaceous rocks, only a single Chalk species (*Terebratulastriata*) surviving into the English Tertiary deposits. The Tertiary rocks were therefore very naturally looked upon at first as being mere local deposits of no great thickness, laid down under conditions totally different from those in which the earlier systems were deposited, and the stratigraphical and biological break between the Cretaceous and Tertiary was held to be one of the greatest in the geological record. The progress of discovery, however, has not only greatly modified these hasty views, but has shown that to a certain extent they are largely erroneous. The thin and more or less unconsolidated Tertiary strata of Britain, when followed to other parts of the world, are found to be represented by sheets of solid limestones, sandstones, and grits, thousands of feet in thickness: and to have been upheaved, as in the Alps and Himalayas, to heights of between 15,000 and 16,000 feet above the sea-level. Nor is the break between the Cretaceous and Tertiary any grander or more universal than that between any of the locally unconformable systems of older date. In the great mountain-ranges of central Europe the systems pass one into the other, and it is practically impossible to draw the line, either physically or palæontologically, between them. In America the richest and thickest of the fossiliferous sediments of the Western States show palæontological characters

common to both systems, so that it is impossible to say whether they are Cretaceous or Tertiary. In thickness of sediment and in the amount of time it represents, the Tertiary is not, perhaps, equal to any of the older systems; but in variety of organic remains and in the evidences it still affords us of enormous and widespread geographical changes, it is by far the most important. Our present great mountain-ranges in the Old World—the Alps, the Pyrenees, the Lebanon, the Himalayas—all came into existence as such in Tertiary times, or at any rate underwent their final and grandest upheaval. But while in the older formations we have (with few exceptions) mainly examples of marine strata, or of such strata as have been protected in regions of depression, we find among the Tertiary rocks numberless basins and isolated areas of estuarine or shallow-water deposits, so recently upheaved above the sea-level that their strata have not yet had time to be swept away. Two of such basins exist in England—the basin of London and the valley of the Thames, and the basin of Hampshire and the Isle of Wight. The strata of these two basins were probably originally continuous, but are now separated by the anticlinal axis of the Weald. They exhibit a full development of Eocene and Oligocene strata, shales, clays, and sandstones of marine, estuarine, and fresh-water origin. In the Miocene period, however, our region appears to have been elevated far above the sea-level, and to have been more or less denuded, and it is only in later Tertiary time that we again find evidences of depression in the curious “*Crags*,” or shelly sands and gravels (Pliocene) of the eastern counties. The following table gives in outline the nomenclature and parallelism of the English Tertiary rocks:—

## UPPER TERTIARY.

PLIOCENE.	{	Upper.	{ Forest Bed. Norwich, Chellesford, and Red Crags.	{	Norfolk and Suffolk.
		Lower.	White or Coralline Crag.		

MIocene. (Absent in Britain.)

## LOWER TERTIARY.

OLIGOCENE.	{	Upper.	(Absent.)	{	Isle of Wight.
		Middle.	{ Hempstead Beds. Bembridge Beds.		
		Lower.	{ Osborne and St Helen's Beds. Headon Beds.		

	Hampshire Basin.	London Basin.
EOCENE.	Upper.	Barton Beds.
		Upper Bagshot Sands.
	Lower.	Bracklesham and Bournemouth Beds.
		Middle Bagshot.
		Lower Bagshot.
		London Clay.
		Lower London Tertiaries.

## EOCENE.

270. The base of the Eocene in the London basin is formed by the so-called *Thanet Sands*—pale sands with grains of glauconite, and having a seam of green coated pebbles at the base. They are essentially a marine formation; the chief fossils are Lamellibranchs (*Pholadomya Koninckii*) and Gastropods (*Scalardia Bowerbankii*). They do not occur in the Hampshire basin. Above them follow the so-called LOWER LONDON TERTIARIES, sheets of sand, pebbles, plastic clay, and loam. In some districts they are of marine origin (East Kent), in others, estuarine (*Woolwich beds*, West Kent), in others, unfossiliferous Plastic Clays (*Reading beds*). Their fossils are thus locally marine (*Cyprina Morrisii*, *Cardium Laytoni*), estuarine (*Ostrea bellovacina*, *Paludina lenta*), or land-derived (*Ficus*, *Laurus*, &c.) Next follows the *London Clay*, a thick deposit (500 feet) of grey or brown stiff clays, with septaria, a shallow water formation, apparently laid down in a marine area, not far from the estuary of a large river, by which plants (*palms*, *fig*, *almond*, *magnolia*) and the carcasses of animals (*crocodiles*, *opossums*, *tapirs*, &c.) were brought down and deposited side by side with marine shells (*Voluta nodosa*, *Atruria ziczac*, *Oliva*, *Conus*, *Cypræa*, &c.) The climate of the period appears to have been distinctly tropical. Above the London Clay follow the *Bagshot Sands* (300 feet), a series of loose sands, sandstones, and greenish clays, with few fossils (*Cardita striata*, and *Nummulites lævigatus*, &c.) In the Hampshire basin the Eocene groups of the London area are represented by the *Plastic Clays*, *Bognor beds*, and *Lower Bagshot series*—all marine. The higher Bagshot Sands have their equivalents in the *Bracklesham beds*, which are crowded with marine fossils (*Voluta ambigua*, *Cardita planicosta*, *Nummulites lævigatus*, &c.), and the Bournemouth beds, which have long been famous for the abundance and variety of their plant remains (*Cactus*, *Araucaria*, *Oak*, *Fig*, *Eucalyptus*, &c.)

## OLIGOCENE.

No Oligocene strata occur in the London basin, but they are well exhibited in the Isle of Wight, where they consist of about 500 feet of sands, clays, and thin limestones, and form-

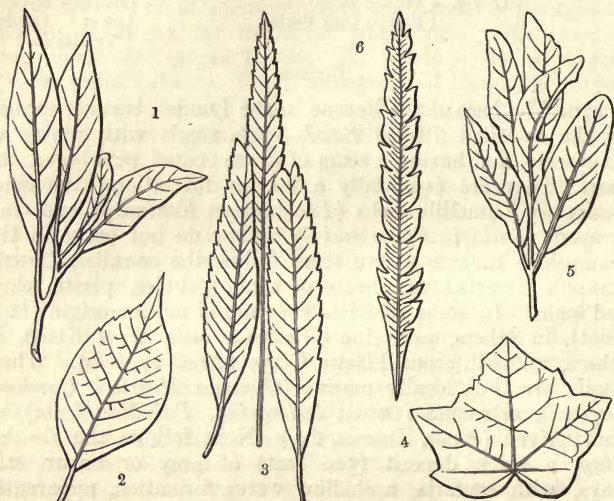


Fig. 138.—Tertiary Leaves from the Bournemouth Beds. (After J. S. Gardner.)  
1, 2, *Beech*; 3, *Laurel*; 4, *Maple*; 5, *Oak*; 6, *Dryandra*.

ing the highest Tertiary beds of the area. Some of the beds are of marine, others of brackish water, and others distinctly of fresh-water origin. They are divided into a lower (*Headon*), a middle (*Bembridge*), and an upper series (*Hempstead beds*). The most characteristic fossils are *Paludina lenta*, *Bulimus ellipticus*, and *Chara tuberculata*, in the fresh-water beds; and *Cerithium plicatum*, *C. elegans*, *Cyrena semistriata*, *Rissoa Chastelli*, in the brackish and marine zones—fossils common to the Oligocene beds of the European Continent.

## PLIOCENE.

The Miocene, as we have already intimated, is absent in England, but small patches of Pliocene deposits occur in the eastern counties. These consist of shelly sands, laminated clays, gravels, reposing unconformably upon the local Chalk and Miocene series, and known as “Crag”—i.e., Pliocene shell-

banks, laid down off shore, and affording evidence of a certain amount of depression of the area in Pliocene times. The lowest is the *White* or *Coralline Crag*, so called from the abundance of its fossil *Polyzoa* (or coral-like Molluscoidea). Next follows the *Red Crag*, a dark-brown shelly sand, 25 feet thick. This is succeeded by the *Norwich* or *Mammaliferous Crag*, abounding in the bones of mammals. Of somewhat later age are the *Chillesford beds*, 5 to 15 feet thick. These several deposits show a gradual coming on of Arctic conditions, the number of northern shells increasing as we ascend the series, from 5 per cent in the White Crag to 75 per cent in the Chillesford Beds. In the lower groups the most characteristic fossils are *Voluta Lamberti*, *Trophon antiquum*, *Fusus contrarius*, *Terebratula grandis*. In the Norwich beds these are replaced by the northern shells, *Astarte borealis*, *Nucula Cobboldii*, *Cyprina Islandica*, &c. The latest deposit of the group is the so-called *Forest bed*, a thin zone of estuarine and marine clays and silt, with layers of peat, and traces of an old land surface, and drifted stumps of trees (hence the name). Like the Norwich Crag, it contains abundant northern marine shells, and bones of extinct animals (*Elephas antiquus*, *E. primigenius*, *Ursus spelæus*, &c.), and also plant remains (Scotch fir, spruce, oak, hazel, &c.)

#### VOLCANIC ROCKS.

The foregoing are the strata which occur in the more or less typical area of the south-east of England; but though Tertiary strata, at least of Eocene date, once probably covered large areas elsewhere in the British Islands, little now remains. At Bovey Tracey, in Devonshire, a patch of lignitiferous strata fills up an old lake basin, which, judging from the character of the abundant plant remains, appears to be of Lower Tertiary date. An enormous series of volcanic rocks occurring in Skye, Mull, and Antrim appear to be of about the same age. They consist of old volcanic piles (still of great height, although much denuded), successive outflows of basalt covering thousands of square miles (familiar to us in the picturesque localities of Staffa and the Giant's Causeway, &c.), and basaltic dykes (some of which cross Britain almost from sea to sea). The basaltic lava sheets were clearly poured out upon solid land, and the date of their emission is fixed, as in Mull and Antrim, by the intercalated "leaf-beds,"—the sites of ancient lakes or ponds invaded by the lava flows, and affording in the

plant remains found in their clay beds evidence that they are of the same age as the Bournemouth beds, or but little later (Oligocene). In the Tertiary rocks of north Greenland, Iceland, and Spitzbergen, a rich Tertiary flora occurs—the *Sequoias* (like the modern *Wellingtonia*) *Magnolias*, *Beeches*, *Walnuts*, and *Limes*, found in these beds, like the tropical shells of the British deposits, affording abundant evidence of the high temperature of the northern hemisphere in Eocene times.

#### FOREIGN TERTIARY ROCKS.

271. In central Europe, as in Britain, the Eocene rocks were laid down in comparatively shallow waters. In the Paris basin the London Clay is absent, and the middle Eocene is formed by the well-known Paris Limestone (*Calcaire grossier*). To the south of the great mountain axis there occurs the great Eocene formation of the Nummulitic Limestone, so called from the *Nummulites* (Lat. *nummus*, a coin) or foraminiferal

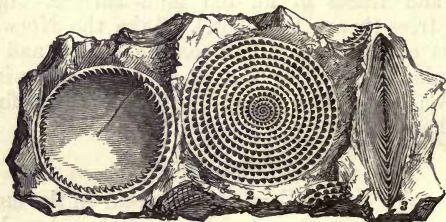


Fig. 139.—Fragment of Nummulitic Limestone, showing—1, An entire *N. levi-gata*; 2, Section with cell-arrangement; and 3, Transverse section.

shells, of which it is largely composed. This formation, thousands of feet in thickness, stretches along the basin of the Mediterranean, extending northwards to the Alps and Caucasus, and south to the Atlas and the Sahara. It is continued through Egypt, Palestine, Persia, Afghanistan, and along the Himalayas to the farthest confines of India. After the deposition of that limestone, probably in a broad open sea, extending from the Atlantic to the Indian Ocean, much of the sea-floor was upheaved, and its consolidated strata bent into those mighty earth-wrinkles which constitute our grandest existing mountain-chains. Into their composition the Nummulite Limestone enters largely, and has been lifted up in the Alps to 10,000 feet above the sea-level, in the mountains of Tibet to heights of at least 13,500 feet. Their chief

elevation took place in Oligocene times, and the upward movement, with occasional intervals of depression, probably went on to the end of Tertiary times. But between the main ridges there were local areas of relative depression. Such is our present Mediterranean; and such too were certain shallow seas, gulfs, and broad lakes of Oligocene and later age, the upheaved strata of which occur in Auvergne, north Switzerland, at Vienna, &c., exceedingly rich in fossil remains, and affording us striking evidence of the excessive luxuriance of the vegetable and animal life of lower and middle Tertiary times. In the Miocene period, when Britain attained its highest Tertiary elevation, the sea again invaded parts of central Europe, and a great fringe of volcanoes, which had arisen in Alpine regions in Oligocene times, stretched in an almost continuous band from central France (Auvergne), through the Rhine Provinces to Bohemia and the eastern Carpathians.

In Pliocene times, the Alps received their final and greatest elevation, the newly formed Pliocene strata were ridged up in the flanks of the Apennines, and a new chain of volcanoes broke out along the edge of the Mediterranean,—Etna, Somma (Vesuvius), Santorin, and a host of others, in a few of which, even at the present day, an occasional eruption gives evidence of their still slowly expiring energies. In India there is a complete series of Tertiary formations (12,000 to 15,000 feet); the latest of marine origin being of Miocene date. The Indian Pliocene rocks are sandstones, conglomerate, and clays (*Sivalik beds*) of fluviatile origin, laid down along the outer skirts of the Himalayas, and remarkable for the abundance of their extinct mammalia (*Sivatherium*, *Elephas*, *Hippopotamus*, &c.) In North America marine Tertiary beds floor all the middle parts of the Mississippi basin, from New Orleans back to St Louis. The Rocky Mountain ranges, like those of the Alps, underwent their last upheaval in Tertiary time. They show enormous thicknesses (13,000 feet) of fresh-water strata of Eocene, Miocene, and Pliocene ages, with abundant plant and mammalian remains (*Miohippus*, *Lophiodon*, *Rhinoceros*, &c.)

272. As already stated, the organic remains of the Tertiary System are all of Cainozoic types. Of course since the commencement of the Eocene period many forms of life have died away, or have become locally extinct: and it is to these extinct forms, rather than to those still surviving, that we shall chiefly direct our attention. The FLORA of the Eocene rocks

of Britain is distinctly indicative of a warm climate. It was rich in southern forms, but contained in addition many recent temperate genera. Among the former were Palms (*Sabal*),

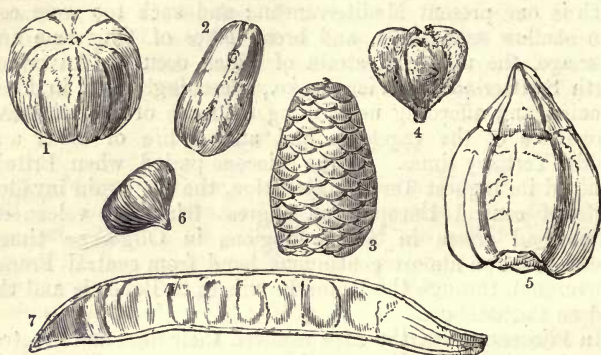


Fig. 140.—Tertiary Fruits: 1, *Cucumites variabilis*; 2, *Faboidea semicurvilinearis*; 3, *Petrophiloides variabilis*; 4, *Cupania lobatus*; 5, *Nipadites cordiformis*; 6, *Leguminites dimidiatus*; 7, *Mimosites Browniana*. London Clay.

and *Nipadites* (like the *Nipa* of Bengal), *Proteacea*, an Australian and South African tribe (*Petrophiloides*), *Melon*, *Almond*, *Eucalyptus*, *Magnolia*, *Cactus*, &c.; among the latter, *Willows*, *Maples*, *Beeches*, *Oaks*, and *Elms*. In the older beds many plants belong to modern Australian, as the later beds to modern American types. Not only are leaves preserved in abundance (fig. 138), but also fruits and seeds (fig. 140). In the Pliocene deposits of Europe, we find the extreme southern forms gradually disappearing, and their place taken first by North American and East Asian types, and finally, wholly by the ancestors of our present European flora.

273. Coming to the Fauna of the British Tertiary rocks, we find all the chief INVERTEBRATE classes represented. The shell-fish are markedly related to those of modern seas: the proportion in each successive sub-fauna, fixing, according to Lyell's original scheme, the place of the containing rocks in the general series. Thus:—

(Glacial) or Pleistocene, . . .	above 95	per cent of living species.
Newer Pliocene, . . .	90 to 95	" "
Older Pliocene, . . .	35 " 50	" "
Miocene, . . .	17	" "
Eocene, . . .	3½	" "

Of the Foraminifera the chief were the coin-shaped *Nummulites*, of which the widely spread *Nummulite Limestone* is composed. The insect life of the time was highly varied, as

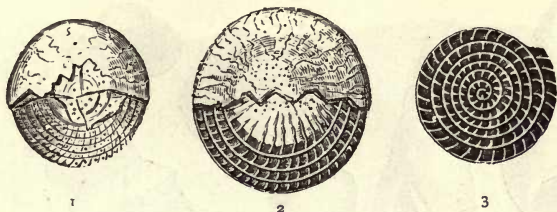


Fig. 141.—1, 2, *Nummulites lævigata*; 3, Section of do.

evidenced by the numberless fossil insects yielded by the deposits of the Tertiary lakes of Switzerland. Gasteropods are abundant fossils in the British Eocene rocks, and belong largely to genera now inhabiting the waters of tropical seas—*Oliva*, *Conus*, *Mitra*, *Cyrena*, *Voluta*, *Cerithium*, *Fusus*,

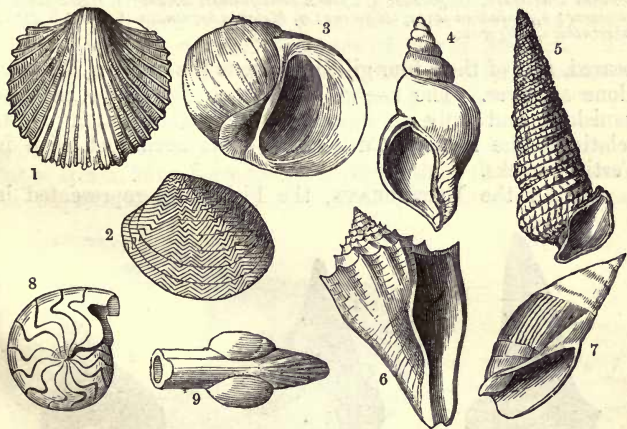


Fig. 142.—1, *Cardium porulosum*, Eocene; 2, *Nucula Cobboldia*, Pliocene; 3, *Natica sigeratina*, Eocene; 4, *Fusus contrarius*, Crag; 5, *Cerithium elegans*, Oligocene; 6, *Voluta Solandri*, Eocene; 7, *Ancillaria buccinoides*, Eocene; 8, *Nautilus ziczac*, Eocene; 9, *Belopsepia Cuvieri*, Eocene.

*Natica*. Of fresh-water shells we have *Limnæa*, *Paludina*, *Planorbis*, and of terrestrial forms, *Helix*, *Pupa*, *Clausilia*, &c., so slenderly represented in earlier epochs. The Bi-

valves (or Lamellibranchs) are almost equally abundant, and their genera are all those of modern types—*Cardita*, *Cardium*, *Leda*, *Cyrena*, *Ostrea*, &c. The Ammonites have all disap-

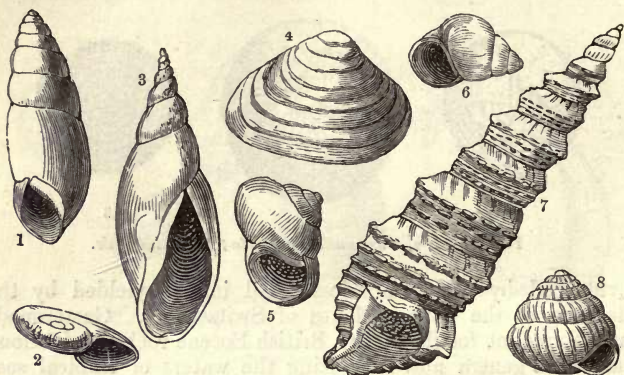
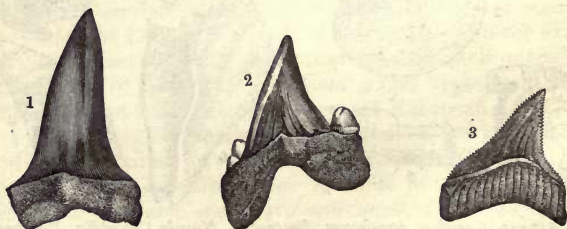


Fig. 143.—1, *Bulimus ellipticus*, Oligocene; 2, *Planorbis discus*, Oligocene; 3, *Lynnea longiscata*, Oligocene; 4, *Cyrena cuneiformis*, Eocene; 5, *Helix occlusa*, Oligocene; 6, *Paludina lenta*, Oligocene; 7, *Melania inquinata*, Eocene; 8, *Helix labyrinthica*, Oligocene.

peared, and of their four-gilled relations the modern *Nautilus* alone survives. The two-gilled Jurassic Belemnite has also vanished, and only an occasional internal skeleton of its relatives—the modern Cuttle-fishes—has been met with in Tertiary rocks.

274. Of the VERTEBRATA, the Fishes are represented in



Figs. 144.—Teeth of Sharks: 1, *Oxyrhina xiphodon*; 2, *Otodus obliquus*; 3, *Carcharodon productus*.

Britain mainly by abundant detached teeth of Sharks (*Otodon*, *Carcharodon*, &c.); but the foreign fish-bearing strata afford abundant evidence that the majority of Tertiary genera are

Teleostian. Among the Reptilia the distinction between the Mesozoic and Cainozoic faunas is remarkable—the great Sauroids (*Ichthyosaurs*, *Mosasaurs*, *Deinosaurs*, &c.) have all disappeared; and we find serpents (*Palæophis*), crocodiles

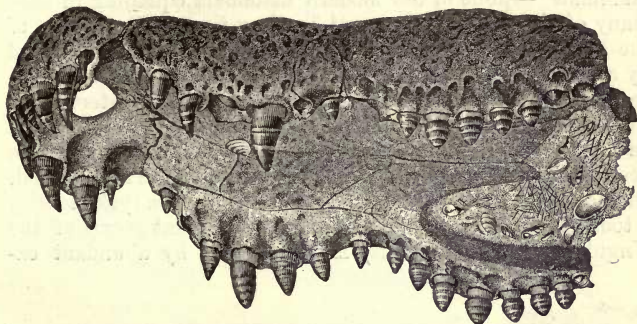


Fig. 145.—Upper jaw of Alligator. Eocene Tertiary, Isle of Wight.

(*Gavialis Crocodilus*), turtles, and tortoises. Of Birds, several genera have been obtained from the Paris beds, and others more recently from the Tertiaries of North America. The Eocene conglomerates of Meudon have yielded remains of a gigantic bird (*Gastornis Parisiensis*), apparently intermediate between the swimmers and runners, the leg-bone indicating a bulk fully equal to that of the ostrich; and in later strata have been found several others that would seem to be connected with the buzzard, quail, curlew, albatross,

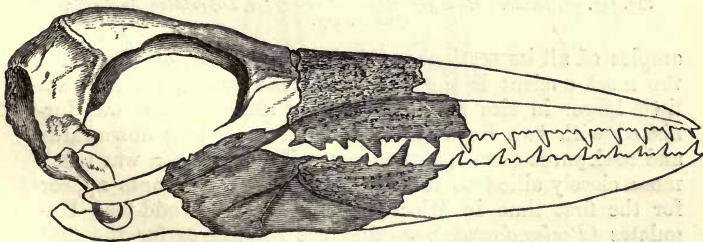


Fig. 146.—Skull of *Odontopteryx toliapicus*, restored. (After Owen.)

kingfisher (*Halcyornis*), pelican, vulture (*Lithornis*), condor (*Pelagornis*), flamingo, parrot, and secretary-bird. To these may be added a dentigerous or toothed bird (*Odontopteryx*),

from the London clay of Sheppey, described in 1873 by Professor Owen.

275. Of the larger Mammalia, the Tertiary System was the culminating epoch, so that it is sometimes called the "Age of Mammals"—none of our modern mammals equalling in bulk many of the gigantic forms of Tertiary time. The group of the Marsupialia, or pouched Mammalia, is poorly represented by a few species allied to the opossum (*Didelphys*) and kangaroo. Of the order of the Edentata (sloths, ant-eaters, &c.), we find in the European rocks the *Macrotherium* of France and *Ancylotherium* of Greece—the latter of which must have been as large as a modern rhinoceros. *Cetacea* are represented, among others, by the remarkable genus *Zeuglodon* (yoke-tooth), a toothed whale about 70 feet long. The great group of the Ungulata (hoofed animals) is represented by abundant ex-

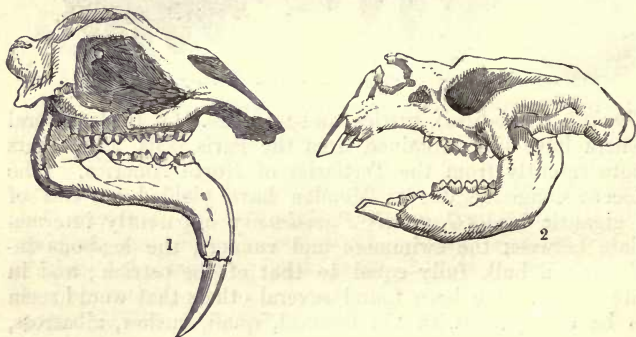


Fig. 147.—1, *Deinotherium giganteum*, Tertiary; 2, *Diprotodon Australis*, Quaternary.

amples of all its sections. Of the *Proboscidea*, or elephants, the most ancient is the Miocene *Deinotherium*, which was a little larger in size than the modern elephant, and was furnished with two huge tusk-like teeth projecting downwards and backwards from its lower jaw. The *Mastodon* was much more closely allied to the elephant. True elephants appear for the first time in Miocene strata. Of the odd-toed Ungulates (*Perissodactyla*), we find the *Rhinoceros* for the first time in European Miocene deposits, but it was apparently hornless. *Tapirs* of various forms occur in deposits of Eocene age in Europe, and in Miocene beds in America; and an allied form, *Brontotherium*, furnished with horns. Nearly allied to the tapirs were the curious *Palæotheria*, herbivorous creatures

(the various species of which differed in size from a hare to that of a horse), furnished with a short proboscis or trunk. From the North American relatives of these forms we seem to

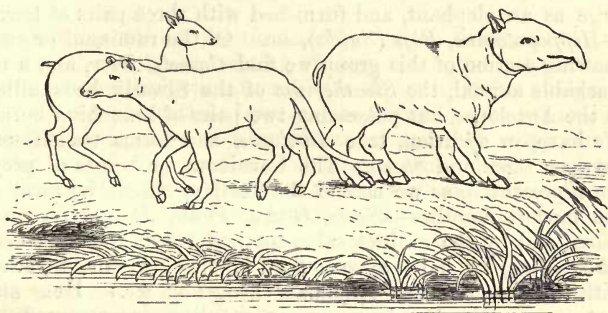


Fig. 148.—Restored Outlines.—*Xiphodon*, *Anoplotherium*, *Palæotherium*.  
Oligocene Tertiaries of Paris Basin.

pass, almost insensibly, to the modern horse, *Equus* (which is itself not found until the Pliocene), through the related Tertiary genera, *Eohippus* (four toes, one rudimentary), *Oro-*

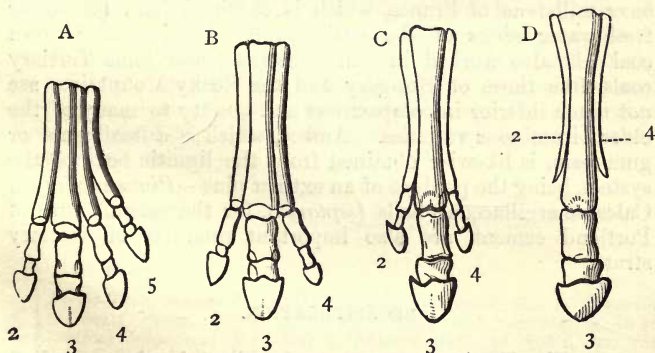


Fig. 149.—Skeleton of the Foot in various forms belonging to the family of the Equidæ.—A, Foot of *Orohippus*, Eocene; B, Foot of *Anchitherium*, Miocene; C, Foot of *Hipparion*, Pliocene; D, Foot of Horse (*Equus*), Pliocene and Recent. The figures indicate the numbers of the digits in the typical five-fingered hand of Mammals. (After Marsh.)

*hippus* (four-toed), *Miohippus* (three-toed), *Hipparion* (three-toed, two lateral ones apparent, but useless), to *Equus* (central

toe only, lateral toes represented by splint-bones). Of the *Artiodactyla* (even-toed ungulates) we find the *Anoplotherium* (a transitional form between the Swine and the Ruminants) and the *Dinoceras* of the American Eocene—an animal as large as an elephant, and furnished with three pairs of horns—*Hippopotamus*, *Pigs* (*Suida*), &c. Of the ruminant or cud-chewing section of this group we find *Camels*, *Deer*, and a remarkable animal, the *Sivatherium* of the Siwalik beds, allied to the Antelopes, but possessing two pairs of branching horns. We have, in addition, true *Antelopes*, and forms transitional between *Oxen* and *Sheep*. The Carnivora, or beasts of prey, are represented, as we ascend the Tertiary stages, by most of the modern families—*Seals*, *Otters*, *Foxes*, *Bears*, *Hyænas*, *Lions*, and by the extinct sabre-toothed tiger (*Machairodus*). *Cheiroptera*, or bats, appear first in the Miocene, together with the Insectivorous Mammals (hedgehog, &c.) Here also first appear the *Quadrumanæ*, or monkeys, represented by *Pliopithecus* and *Dryopithecus*—the latter apparently living in trees and on fruits, and equalling man in stature.

276. The industrial products of the system are building-stones and marbles of various quality; pipe and potter's clay in abundance; sands and gravels for various uses; gypsum, or the well-known "plaster of Paris"; and the highly-valued *burr* millstone of France, which is obtained from the upper fresh-water series of the Paris basin. Lignite or "brown coal" is also worked in many districts, and some Tertiary coals, like those of Hungary and the Rocky Mountains, are not much inferior in compactness and quality to many of the older bituminous varieties. Amber, which is a fossil gum or gum-resin, is likewise obtained from the lignitic beds of the system, being the produce of an extinct pine—*Pinus succinifer*. Calcareo-argillaceous balls (*septaria*), for the manufacture of Portland cement, are also important products of Tertiary strata.

#### RECAPITULATION.

277. The Tertiary system, as described in the preceding chapter, embraces all the regular strata and sedimentary accumulations which lie between the Chalk and the close of the Glacial or Drift Formation. Its organic remains are all of recent or *Cainozoic* types, and it has been subdivided into four groups, according to the numerical amount of existing species found embedded in its strata, thus—

Pliocene—	fossils showing a majority of existing species.
Miocene—	" " a minority of existing species.
Oligocene—	" " a few existing species.
Eocene—	" " the dawn of existing species.

In their mineral composition and succession these groups present great variety—consisting of clays, sands, marls, calcareous grits, limestones, gypsum, and beds of lignite, with evidences of frequent alternations from marine to fresh-water conditions. On the whole, clays and limestones prevail, and many of the latter are of very peculiar character, as the fresh-water burr-stones of Paris, the gypsum or sulphate-of-lime beds of Montmartre, the diatomaceous tripoli of Bohemia, and the nummulitic limestone of the Alps, Egypt, and India. Separating the British and northern Tertiaries from the southern group, it may be said that the former appear often confined to limited areas, as if originally deposited in inland seas, lakes, and estuaries. These well-defined districts are usually termed “basins,” although some have certainly received much of their present shape by earth-movements subsequent to the deposition of their strata; hence the repeated allusions to the London and Paris basins, in which there are also frequent alternations of marine and fresh-water beds, as if at certain stages fresh-water conditions had prevailed in the areas of deposit. The Tertiaries of England, France, Belgium, Switzerland, and Germany are those that have been most fully investigated, and though differing in the composition and succession of their strata, are generally regarded as finding their equivalents in those of Britain, which may be briefly grouped as under:—

UPPER TERTIARY.	BRITISH TERTIARY DEPOSITS.	EUROPEAN EQUIVALENTS.
	PLIOCENE.	
	<i>Forest Beds, Mammaliferous Crags, Coralline Crags, and St Earth Beds of Britain.</i>	<i>Ossiferous Beds of Montpellier; Congeria Series of Vienna; Sub-Apennine Series of Italy; Siwalik Beds of India, &amp;c. (in part); Crags of Antwerp (in part).</i>
UPPER TERTIARY.	MIOCENE.	
	Absent in Britain.	<i>“Faluns” of Central France; Upper Fresh-water (Eningen) and Marine Molasse of Switzerland. Cerethium and Mediterranean Beds of Vienna. Lower Black Crags and Sands of Belgium.</i>

LOWER TERTIARY.	OLIGOCENE.		
	(Absent.)		
	<i>Hempstead Beds.</i>	Paris Basin.	<i>Gres de Fontainebleau.</i>
	<i>Bembridge Beds.</i>		<i>Calcaire de Brie.</i>
	<i>Headon Beds.</i>		<i>Sables d'Etampes.</i>
			<i>Lacustrine Marls.</i>
			<i>Brown Coal Series of Germany.</i>
			<i>Nagelfluë, Lower Marine Molasse of Switzerland.</i>
			<i>Tongrian and Rupellian Sands and Clays of Belgium.</i>
	EOCENE.		
	<i>Barton Beds.</i>	Paris Basin.	<i>Sables de Monceaux, Beauchamp, &amp;c.</i>
	<i>Bracklesham Beds.</i>		<i>Calcaire Grossier.</i>
	<i>London Clay.</i>		(Absent.)
	<i>Woolwich and Reading Beds.</i>		<i>Lignites du Soissonais.</i>
	<i>Thanet Sands.</i>		<i>Sables de St Omer.</i>
	(Wanting.)		<i>(Mons Limestone of Belgium.)</i>
			<i>Macigno of Italy.</i>
			<i>Nummulate Limestone, &amp;c., of South Europe, &amp;c.</i>
			<i>Vienna Sandstone (in part).</i>
			Clays and Sands of the Belgian area.

278. The organic remains of the system belong in greater part to existing species, and thus among the plants we find the leaves, fruits, and seed-vessels of palms and other monocotyledonous plants, and an abundance of fossil remains of true exogenous timber trees; while among the animals we discover species of almost every existing order, invertebrate and vertebrate. The most characteristic feature of the fauna is the abundance of gigantic quadrupeds—of *Mastodons*, *Elephants*, *Rhinoceroses*, *Deinotheriums*, *Palæotheriums*, &c. In respect of all its fossils, the Tertiary era exhibits a remarkable difference compared with those of the Chalk, Oolite, or Carboniferous. During these epochs the plants and animals in every region of the globe presented a greater degree of sameness—whereas during the Tertiary epoch, geographical distinctions and separations more like those now existing began apparently to prevail: hence the difference between the Tertiary mammals of Europe and those of South America, which represent its present sloths, ant-eaters, and armadillos. Whatever the conditions of other regions during the deposition of the Tertiary strata, we have evidence that in the latitudes now occupied by England and France a tropical or sub-tropical temperature prevailed in Lower Tertiary times, which was succeeded in Upper Tertiary times by more temperate conditions; and finally, at the close of the Pliocene, by those of the extreme boreal or glacial characters which gave origin to the great Boulder-clay or Drift formation.

## SECTION VI.

### QUATERNARY OR ANTHROPOZOIC PERIOD.

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#### CHAPTER XXII.

##### PLEISTOCENE OR GLACIAL FORMATIONS.

279. THIS group, as the name implies, is intended to embrace all Post-Tertiary accumulations, the organic remains of which, while they are chiefly referable to existing species, nevertheless include some that are either wholly or locally extinct. In the present state of geological knowledge, it is impossible to define with precision the limits of Pleistocene deposits, and all that can be attempted is to arrange under this head the clays, sands, gravels, and boulders generally known as the "Drift or Glacial formation." As a whole, there is no class of rocks more perplexing, or whose origin is involved in greater obscurity, than this "Drift" or "Boulder-clay"—the "Diluvium" of the earlier geologists. Resting everywhere unconformably upon everything below, it is composed in some districts of irregular ridges and mounds of sharp gravelly sand; in others, of expanses of pebbly shingle; and more generally, perhaps, of various-coloured clays, enclosing, without regard to arrangement, water-worn blocks or *boulders* of all sizes, from a pound to many tons in weight,—it is evident that it does not owe its origin to the ordinary sedimentary operations of water. It is also for the most part unfossiliferous; marine shells being found, and that very sparingly, only in certain intercalated sands and clays. When we examine the group as it occurs in Britain, we find it composed in some tracts (central counties of England) of sheets of clay embedded in an open gravelly drift, consisting of fragments

of all the older rocks up to the Chalk, masses of which, thousands of tons in weight, are embedded in it. In other districts, as the middle counties of Scotland, large areas are covered with a thick, dark, tenacious clay, locally known by the name of "Till," and enclosing rounded and water-worn boulders, as well as angular fragments of all the older and harder rocks—granite, gneiss, greenstone, basalt, limestone,



Fig. 150.—Cutting through Boulder-Clay, Linlithgowshire.—From a Photograph.

and the more compact sandstones. The boulders are of all sizes, are sometimes rounded and water-worn, sometimes sharp and angular, sometimes smoothed and striated, and are

distributed throughout the mass without regard to sedimentary deposition. In other localities, both in England and Scotland, we find large areas covered by loose rubbly shingle and sand; the shingle and sand often appearing in mound-like ridges, or in flat-topped irregular mounds (the *kaimes* of Scotland, the *eskars* of Ireland, and *ösars* of Sweden). Occasionally districts are thickly strewn with boulders or erratics which rest on the glacial deposits, or even on the bare rock-formations, without any accompanying clays or sands; and at times only a single gigantic boulder ("perched block") will be found reposing on some height, as sole evidence of the drift formation. When we come to examine the clays and sands more minutely, we find them partaking less or more of the mineral character of their respective districts. Thus, the boulder-clays of our coal districts, though thickly studded with boulders of distant origin, are usually dark-coloured, and contain fragments of coal, shale, and other Carboniferous rocks. The same may be remarked of Old and New red sandstone areas, where the clays are usually red; and of Oolitic and Chalk tracts, where they assume a yellowish or greyish aspect.

280. In addition to what has been stated respecting the composition of the drift, it may be remarked that the sands seldom exhibit lines of stratification, and that the clays are rarely laminated. Occasionally sands and clays alternate, or a dark-coloured clay may be overlaid by a lighter-coloured one; but more frequently sands and clays occur *en masse*, enclosing curious "nests" or patches of gravel, and crowded accumulations of boulder-stones, or the alternating clays and sands may be bent and contorted in a variety of ways. On examining the surfaces of many of the boulders we find scratches and groovings, as if they had been rubbed forcibly over each other in one direction; and what is still more curious, the surface of the rocks on which the boulder-clay reposes are often smoothed, and marked with bold linear scratches and furrows, as if the boulders had been forcibly driven forward, and had striated and grooved it during their passage. Again, these scratchings and groovings generally trend in lines parallel to the hill-ranges and valleys in which they occur, or radiate from some high and commanding eminence which has served as a centre of dispersion. Moreover, most of the lower hills, as in Scotland, present a bare, bold, craggy face to the west and north-west, while their slopes to the east and south-east are usually masked with

thick accumulations of clay, sand, and gravel. This appearance, generally known by the name of "crag and tail," must be ascribed to the same moving forces which transported the enormous boulders of the Drift, and furrowed the surfaces of the rock-formations over which they were borne. Taking all these phenomena into account, it is quite clear that the Pleistocene accumulations owe their origin to no ordinary operations of water. We can conceive of no current sufficiently powerful to transport boulder-blocks of many tons in weight over hill and dale for hundreds of miles; of no sedimentary condition that would permit boulders and clays to be huddled up in the same indiscriminate mass; while the smoothing and grooving of rock-surfaces point not to any violent cataclysm, but to long-continued action. There is only one set of physical conditions with which we are acquainted sufficient to account for all the phenomena—namely, an arctic or frozen climate like that of modern Greenland, with a continental ice-sheet to wear and smooth and furrow the surface of the land, and with icebergs and ice-floes dropping off-shore to transport the eroded material into deeper water; and it is now to such conditions that geologists turn for a solution of the boulder-formation—to ice acting not only altitudinally as the *Glacier*, but latitudinally as the *Ice-sheet* or *Ice-mantle*.

281. After the deposition of the Pliocene, it would seem that the whole of northern and western Europe, including the British Islands, was buried under a vast continental ice-sheet of the same character as, but vastly larger than, the ice-sheets which exist at present in Greenland and upon the Antarctic continent. This ice-sheet attained its greatest thickness in Scandinavia, and spread out thence to the south, south-east, and south-west, as far as the central parts of England, Germany, and Russia. The Baltic Sea and German Ocean became gradually filled with solid ice, which overrode most of the British Islands, and extended far into the Atlantic, where the outer edges of the ice probably broke off in immense icebergs. The ice in Scandinavia appears to have been between 5000 and 6000 feet in thickness, and is calculated to have attained a depth of 3000 or 4000 feet in the Scottish Highlands. The *Till* seems to have been the great "ground moraine" of the ice-sheet; the "*Boulder-clay*" the mixed morainic material it left behind. The boulders in the till and clays allow us to follow in imagination the chief directions in which the ice-masses moved over this region. The whole of the low grounds between Hamburg and Moscow

is floored by rock-rubbish brought mainly from Scandinavia—an amount more than sufficient to refill the Baltic; some of the Scandinavian rocks were even carried to England. In Britain itself we find the abundant boulders of the metamorphic Highland rocks spread out over the low grounds of central Scotland; those of the igneous rocks of Galloway and the Lake District scattered over much of the Midland area of England; and those of Lincolnshire, &c., mixed tumultuously together in the Norfolk clays.

282. Of the gradual coming-on of the first great ice-sheet few evidences remain to us; but we find towards the middle of the Glacial epoch that much of Britain became *submerged* to a great depth—glacial sands with Arctic shells being found at heights of 1300 feet in Wales (Moel Tryfaen), at 1200 feet in Cheshire (Macclesfield), and at 524 feet in Scotland (Lanarkshire). How long this depression lasted, or over what broad areas it actually extended, it is impossible at present to determine. But ultimately a gradual re-elevation of the submerged lands took place. Our mountain-ranges and hill-tops emerged as islands, and our valleys as firths and straits. These islands, as they emerged, were again covered with ice-glaciers, which smoothed the hillsides; icebergs and ice-floes ground their way through the firths, disturbing, adding to, and rearranging the older debris. Finally, the whole region appears to have been elevated even a little higher than its present level, and the great ice-sheet returned. It never, however, appears quite to have attained its first enormous extension. Eventually, it began to shrink away, with many halts and pauses, as the climate ameliorated, leaving behind mounds and heaps of morainic debris at every pause in its retreat. Even after the great ice-sheet had vanished, a few local glaciers still lingered on in the higher recesses of our British ranges, as in the Snowdon, Lake, west Ireland, Galloway, and north Highland districts; and some of their moraines are still as fresh as in the days in which they were deposited. But, finally, even these local glaciers disappeared; Britain slowly assumed its present appearance and climate; and the present Greenland Ice-sheet and the modern glaciers of the Alps and Himalayas are almost all the relics that now remain to us of the continental masses of ice that overspread so much of the northern hemisphere in the "Great Ice Age."

283. The materials left by the various agents at work during the Glacial epoch in Britain and Europe include patches of marine clays and sands, with shells distinctly of a

boreal or northern aspect, and affording unquestionable evidence of the cold conditions of the waters of our seas during glacial times. But in addition to the all-prevailing boulder-

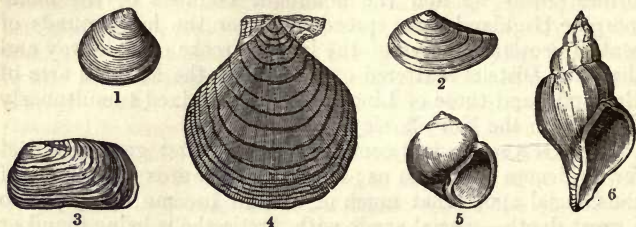


Fig. 151.—Boreal shells in the Upper Drift of the Clyde (Smith).  
1, *Astarte borealis*; 2, *Leda oblonga*; 3, *Saxicava rugosa*; 4, *Pecten Islandicus*; 5, *Natica clausa*; 6, *Trophon clathratum*.

clays and sands which find their natural explanation in the general physical condition of the Glacial epoch, we occasionally discover patches of lacustrine clays, peat, and sand, intercalated among the more heterogenous masses. These intercalated beds contain not only relics of the cold-loving forms—the *mammoth* (or woolly elephant), the woolly *rhinoceros*, the *reindeer*, the *lemming*, &c.—but also the bones of such southern animals as the *hyæna*, the *lion*, the *leopard*, the *porcupine*, and the *hippopotamus*. From this it has been argued that the Glacial or Pleistocene age was not one of purely Arctic conditions throughout, but consisted of alternating periods of intense cold—during which the ice-sheets came southward, and the Arctic fauna prevailed; and of periods of comparative warmth (*Interglacial Epochs*), when the ice-sheet and the Arctic animals retreated and the southern fauna occupied their place.

284. Phenomena corresponding to those characteristic of British glacial deposits occur in many parts of the Northern Hemisphere, in the formations of the same geological date, all pointing in the same general direction. We find evidence that during the Great Ice age the Alpine glaciers united themselves into a continuous ice-sheet, which spread out across the lower grounds of Switzerland, and left its great erratics stranded on the range of the Jura, and far down the valley of the Rhone. In North America, the continental ice-sheet seems to have extended southward in the earlier stages to New York and St Louis. In the second stage it does not appear to have travelled so far southward, but it nevertheless

filled the great Laurentian lakes to overflowing, and spread out in mighty fan-like masses over the region to the south: the great moraines of the later period have been traced far and wide across the continent, from the neighbourhood of Niagara to the Rocky Mountains.

285. Of the *causes* of the glacial epoch little is yet known with certainty, but many theories have been promulgated. By some it has been held that the intense Arctic conditions were owing mainly to some special and peculiar disposition of the sea-and-land areas in glacial times; but the fact that the same boreal conditions appear to have prevailed over all the northern parts of both continents at the same time, has led to the more prevalent opinion that the excessive cold was essentially due to astronomical causes. These constitute the foundations of Dr Croll's well-known theory. Our earth travels round the sun, not in a circle, but in an ellipse, of which the sun occupies one of the foci. At present we have our winter in the northern hemisphere when the earth is nearest the sun (in *perihelion*), but (according to Dr Croll) in the glacial epoch the winter of the northern hemisphere occurred when the earth was farthest from the sun, and also when (owing to the effects of the varying attraction of the planets) the ellipse formed by the earth's orbit was most elongated. The amount of heat received by the northern hemisphere, under these circumstances, was not only largely reduced in amount, but the winter itself was many days longer. At the same time, of necessity, an excessive evaporation was going on in the southern hemisphere, and the main ocean currents would be compelled to shift their ordinary courses. Under all these circumstances the warmth of the comparatively short summer of the northern hemisphere would be insufficient to melt the excessive winter snows, which accumulated until the northern lands were buried beneath the continental ice-cap. But as these severe local Arctic conditions, from corresponding astronomical causes, would be again and again reversed, even while the earth remained at its maximum distance from the sun, the Glacial epoch in the northern hemisphere must have been interrupted by periods of excessive warmth, while the southern hemisphere was undergoing its local phase of glaciation. Such intercalated hot periods are demonstrated, according to Professor James Geikie and others, by the proofs we have already adduced of the alternate presence of the southern and northern faunas within the British area during Pleistocene times.

286. That man himself existed in Europe during Glacial times cannot yet be said to be fully demonstrated. By some geologists, the older cave and river deposits (to be noticed in our next chapter), which yield abundant relics of human workmanship in the form of flint implements, &c., in association with bodies of extinct mammalia—the *mammoth*, *hyæna*, *cave-lion*, *cave-bear*, &c.—are believed to be in reality of interglacial age. If so, man must have beheld the last of the great ice-sheets of northern Europe, and the final phases of the Glacial epoch must be assigned to the Anthropozoic Period.

## CHAPTER XXIII.

## RECENT OR POST-GLACIAL FORMATIONS.

287. HAVING treated the Boulder-drift as the great break that intervenes between the Tertiary and Recent, we now proceed to describe under the term *Recent* or *Post-Glacial* all accumulations and deposits formed since the close of the Glacial epoch. However difficult it may be to account for the conditions that give rise to the "Drift," there can be no doubt regarding the agencies which have been at work ever since in silting up lakes and estuaries, forming peat-mosses and coral-reefs, laying down beaches of sand and gravel, throwing up volcanic hills and islands, slowly submerging some tracts of land, and as gradually elevating others above the waters of the ocean. At the close of the Pleistocene epoch, the present general distribution of sea and land seems to have been established. At the close of that epoch, also, the earth appears to have been peopled by its present flora and fauna, the only subsequent change being some local removals of certain plants and animals, and the extinction of a few species, whose remains are found embedded in a partially-petrified or *sub-fossil* state in Post-Tertiary terrestrial and lacustrine accumulations.

288. In many of the deposits laid down since the Glacial Epoch we find unequivocal evidence of the existence of man, —usually in the form of the implement of stone or metal employed by him in war or in the chase. This branch of geology shades insensibly into the science of Archæology, and the terms employed, and the arguments used, are essentially archæological. It is sufficient, perhaps, to state that archæologists originally divided the history of man's gradual advancement in civilisation into three ages—the

Stone Age, the Bronze Age, and the Iron Age. Aided by geology, they have found it possible to re-divide the Stone Age, into (a) the *Older Stone age* (*Palæolithic*), in which the stone implements employed by man were roughly chipped; and (b) the *Newer Stone age* (*Neolithic*), in which the implements were carefully smoothed and polished. Further, the Palæolithic age has been again subdivided into two sections, an older or *Mammoth age*, in which man's stone implements



Fig. 152.—*Elephas primigenius*, or Mammoth.

are found in association with the bones of the extinct animals of the Glacial epoch (*mammoth*, *cave-lion*, *hippopotamus*, &c.; and a newer or *Reindeer age*, in which the relics of man occur in France and elsewhere in association with bones of the reindeer. But all these ages shade insensibly the one into the other. In some districts stone implements were employed probably long after they had fallen into disuse elsewhere, while even in the later stone ages unpolished tools were probably employed for rough purposes, the smoothed examples being saved for fighting or the chase; while, even up to the present day, stone implements are more or less employed by certain savage tribes. The following is the *chronological* classification of the deposits yielding traces of human workmanship which is generally employed:—

<i>Historic</i> . . . . .	{	The period covered by the records of human history down to the <i>present time</i> .
<i>Pre-Historic</i> . . . . .	{	(c) <i>Bronze and Earlier Iron Age</i> .
	{	(b) <i>Neolithic or New Stone Age</i> .
	{	(a) <i>Palæolithic or Older Stone Age</i> .

289. The deposits in which we find relics of man are all terrestrial or fluviatile in origin—river terraces, cavern de-

posits, lake deposits, peat-mosses, and the like. The remains of man's manufactures, significant of the Palæolithic age, are rough flint implements, axes, and chipped flints. They occur in cavern deposits and old river gravels in association with that curious mixture of the bones of northern and southern mammalia so characteristic of glacial times (*mammoth, cave-bear, reindeer*, with the *lion, lynx, leopard*, and *hippopotamus*), and which has led to the opinion that they are in reality of interglacial age. The men of the later or reindeer section of the Palæolithic time were cave-dwellers and hunters, and have left sketches and carvings behind them showing that they had attained a respectable degree of civilisation. The *Neolithic* implements occur in similar deposits, but usually in layers above the Palæolithic relics. The tools are polished carefully, and the associated animal remains show us that the Glacial fauna had disappeared. One extinct animal survived into the Neolithic age—the magnificent *Irish Elk*; and many

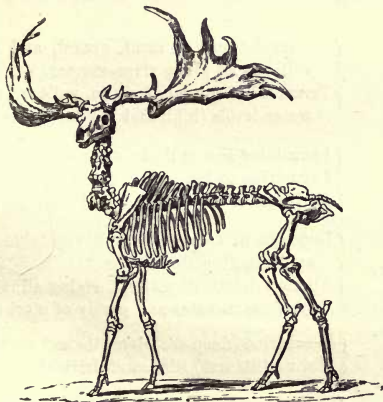


Fig. 153.—*Cervus Hibernicus*, or Gigantic Irish Deer.

forms now absent from Britain and southern Europe were then locally abundant—such as the *reindeer, brown bear*, and *beaver*, &c. Neolithic man had already domesticated the *dog, horse, goat*, and *sheep*, and was acquainted with agriculture, the arts of weaving, and of making pottery. The Bronze and Iron Ages are represented by cairns, sculptured stones, and various objects of human manufacture, and appertain solely to the province of the archæologist.

290. But the deposits yielding evidences of man's existence form only a mere fraction of those laid down since Glacial times. With the exception of volcanic lavas, deposits from calcareous and siliceous springs, some consolidated sands and old coral-reefs, we have, however, few solid strata—the generality of Recent accumulations being clays, silts, sands, gravels, and peat-mosses. As they are scattered indiscriminately over the surface, it is impossible to treat them in anything like order of superposition; hence the most intelligible mode of presenting them to the beginner, is to arrange them according to their composition, and the causes obviously concerned in their production. No doubt, some are very recent and others very ancient, but their relative ages will be better ascertained by their remains than by any order of superposition, which in the case of distant accumulations it is obviously impossible to establish. Looking, therefore, at their nature and origin, the Recent or Superficial Accumulations may be classed as follows:—

FLUVIATILE.	{ Accumulations of sand, gravel, and alluvial silt, in valleys and along river-courses. { Terraces of gravel, &c., in valleys, marking former water-levels (high and low level gravels).
LACUSTRINE.	{ Lacustrine accumulations, now in progress. { Lacustrine or lake silts, filling up ancient lakes. { Shell and clay marl, formed in ancient lake-basins.
FLUVIO-MARINE.	{ Deposits of sand, silt, and vegetable debris in tidal estuaries, forming deltas. { Ancient deltaic deposits, forming alluvial plains, partly of fresh-water and partly of marine formation.
MARINE.	{ Submarine (deep-sea) deposits and accumulations. { Marine (littoral) silt, sand-drift, shingle, beaches, &c.
CHEMICAL.	{ Calcareous deposits, as calc-tuff, travertine, &c. { Siliceous deposits, as siliceous sinter, &c. { Saline and sulphurous deposits from hot springs, volcanoes, &c. { Bituminous exudations, as pitch-lakes and the like.
ORGANIC.	{ Vegetable—peat-mosses, jungle-growth, vegetable drift. { Animal—shell-beds, coral-reefs, &c. { Soils—admixtures of vegetable and animal matters. { Cavern deposits, and osseous breccias.
IGNEOUS.	Discharges of lava, scorïæ, dust, and other matters.

Carefully reviewing the above synopsis, and bearing in mind what was stated in Chapter II. respecting the causes now modifying the crust of the globe, the student need be presented with little more than a mere indication of these accumulations.

## FLUVIATILE ACCUMULATIONS.

291. Under this head (Lat. *fluvius*, a river) are comprehended all accumulations and deposits resulting from the operations of rivers. Such alluvial tracts as the "carse" and "straths" of Scotland, and the "fens" and "holms" of England, have been formed partly in this way, and partly by upheaval of the deltas and estuaries into which their rivers are discharged. In many of these have been found the bones of elephants, rhinoceroses, wild boars, deer, wild oxen, bears, wolves, beavers, and other animals long since extinct in the British Islands, as well as the remains of seals, whales, and

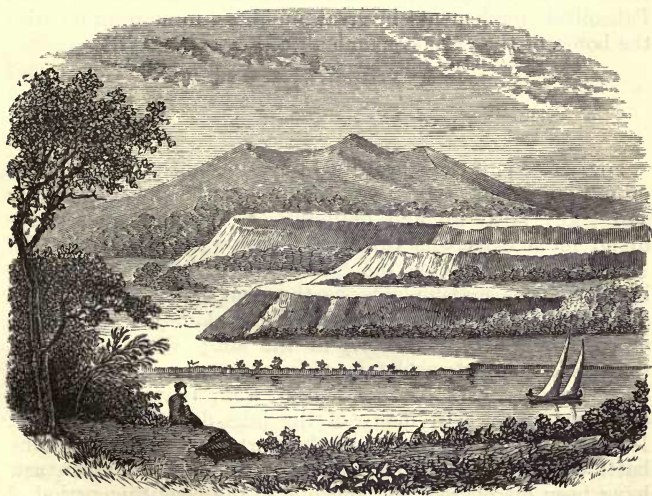


Fig. 154.—Terraces on the Connecticut River, N.H.

other marine creatures which only occasionally frequent our shores. Such accumulations are often of great thickness, and consist for the most part of alluvial silt, masses of gravel and

shingle, with occasional beds of fine dark-blue unctuous clay, and layers of peat-moss and shell-marl. Again, in most of the inland river valleys of this and other countries there appear, belting their slopes, long level terraces, composed of sand, shingle, and silt. Such terraces give evidence of the former water-levels of the river, and point to a time when the plain stood at that level, and before the river had worn its channel down to the present depth. River-terraces must not be confounded with the raised beaches which fringe many parts of our coasts and estuaries; for, though both are in one sense ancient water-levels, the former are local and partial, while the latter are more general and uniform. Besides, the remains found in the one are of terrestrial or fresh-water origin; in the other they are strictly marine. It is usual to distinguish these river-gravels into *low-level* and *high-level*—the former being the more modern, the latter often carrying us back to the time of the mammoth and woolly rhinoceros. Some of the most remarkable of these terraces, from the geological point of view, are those of the Somme in northern France, which have yielded Palæolithic implements in great numbers, in association with the bones of the extinct mammals.

#### LACUSTRINE OR LAKE DEPOSITS.

292. Silted-up lakes are rife in every country, and a great proportion of our alluvial valleys are but the sites of marshes and lakes filled up and obliterated. The organic remains found in lake-deposits are strictly fresh-water and terrestrial—fresh-water shells, as the limnæa, planorbis, and paludina, in the marls; marsh-plants, as the reed, bulrush, and equisetum, in the peat-moss; or terrestrial plants, as the birch, alder, hazel, oak, pine, &c., in the silt; with bones and sometimes complete skeletons of the Irish deer, elk, great red-deer, reindeer, wild ox, horse, bear, wolf, beaver, otter, and other mammals. In many of the lake-deposits of Britain, Ireland, France, Belgium, and Switzerland, tree-canoes, stone battle-axes, bone weapons, and other objects of human art, have been discovered, all pointing to the Neolithic period of archæology, though chronologically of vast antiquity, and far beyond the written records of our race. In European lakes have also been discovered remains of pile-dwellings and artificial islands (the *pfahlbauten* of Switzerland and *crannoges* of Ireland); and along with these, numerous objects of human

art in stone, wood, bone, and horn—some the fabrications of Neolithic races unacquainted with the metals, and living in early prehistoric ages, others the work of the men of the Bronze and Iron ages of a later date.

## FLUVIO-MARINE FORMATIONS.

293. At the mouths, or in the estuaries of existing rivers, there have been accumulating those deposits constituting large expanses of low alluvial land, known as "deltas," the most notable instances of which are those of the Rhine and Po in Europe, of the Nile and Niger in Africa, of the Ganges, Irawaddy, and Chinese rivers in Asia, and of the Mississippi and Amazon in America. As these estuary deposits now vary in their organic remains, so they must have varied since their commencement; and thus, were they thoroughly explored, they would afford unerring criteria of any specific changes that may have taken place in the fauna of the current epoch. In regions where there has been little displacement of level, or disturbance of the present distribution of sea and land, these estuary deposits present an unbroken suite from the silts of last tide down to the latest Tertiaries. In all latitudes, however, subjected to the glacial

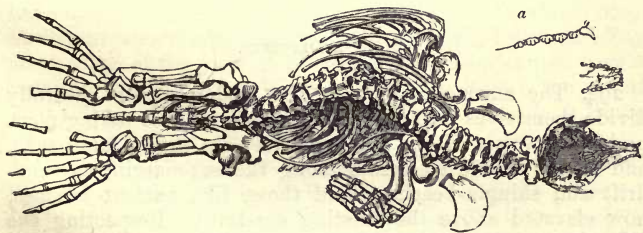


Fig. 155.—Skeleton of Seal (*Phoca vitulina* ?) from the Brick-clay of Stratheden, Fifeshire, 100 feet above existing sea-level; a, Dentition of do.

drift, the line of demarcation is by no means obscure; and hence we can judge of any local removals or general extinctions of species that may have taken place since the close of the Pleistocene period. In the Clyde, Forth, Humber, Thames, and other British estuaries, we find marine shells of species now rare or extinct in these seas; bones of cetacea, seals, and aquatic birds, seldom or never seen in the same latitudes;

tusks, grinders, and bones of *Elephants*, *Hippopotami*, *Elks*, *Urus*, *Bos longifrons*, *Equus fossilis*, *Hyæna*, &c., long since extinct in Europe; and in the more superficial beds (at a depth of from 10 to 20 feet) have been discovered canoes, stone hatchets, and other monuments of the prehistoric human epoch. In other countries the organic remains of these estuary deposits present a somewhat similar gradation, from the

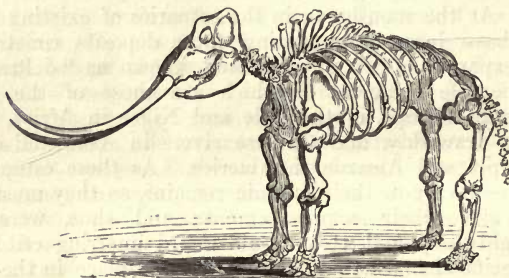


Fig. 156.—*Mastodon*. Upper Tertiary and Quaternary of Northern Hemisphere.

prehistoric period of man back to the times of the *Myiodon*, *Mammoth*, *Mastodon*, and other quadrupeds that lived from the Tertiary into the current period.

#### MARINE DEPOSITS.

294. The marine deposits of the modern epoch naturally divide themselves into three great classes—those taking place under the waters of the ocean, as deep-sea muds, sandbanks, and shoals; those collecting along the sea-margin, as sand-drift and shingle-beaches; and those, like ancient beaches, now elevated above the existing sea-level. Respecting the first class of deposits, we know very little indeed. As examples of marine silt, we may point to the “warp” of the Humber, to the “Fens” and marshes of Lincolnshire and Cambridge, and to the low plains of Holland and Denmark, which are all the immediate formation of the German Sea. Of sand-drift, which is first accumulated by the tides and waves, and subsequently blown into irregular heights and hollows by the winds, we have instructive instances in the *landes* of France along the Bay of Biscay near the Garonne, between Donegal Bay and Sligo Bay in Ireland, and of the

"Links" between the Tay and Eden in Scotland. Of these recently-formed silts and sand-drifts, thousands of acres lie waste and worthless; but of the older portions large tracts have been reclaimed, and are now under the plough of the farmer. Their organic remains are of all ages, from the drift of the last tide to the half-petrified bones of whales and shells of mollusca not now to be found in these seas.

295. All along the shores of the British Islands, as well as along the shores of every other sea, there exists a level margin, more or less covered with sand and gravel. This constitutes the existing *beach*, or sea-margin; but above it, at various heights, are found, following the bays and recesses of the land, several similar margins or terraces known as "ancient or raised beaches." These give evidence of either elevation of the land or depression of the ocean, and point to times when sea and land stood at these successive levels. We have several notable examples along our own coast, at heights about twenty-five, forty, sixty-three, one hundred and twenty feet, and even still higher elevations above the present sea-level; similar indications are found along the coast of Norway, the shores of the Baltic, the coasts of Siberia and Greenland, in the Bay of Biscay, and along the coasts of Spain.

296. As raised beaches point to successive elevations of the land, so do "submarine forests" give evidence of occasional depressions. We say *occasional* depressions, for as yet we have only a single line of these so-called forests, which occur at distant intervals along the Firths of Forth, Eden, and Tay, along some of the bays of Shetland and the island of Lewis, between the Tyne and Wear, at Hartlepool near the mouth of the Tees, at Hull on the Humber, on the coasts of Hampshire, Devonshire, and Lancashire, and at Glasson on the Solway. In general, these submarine forests consist of a bed of peat or semi-lignite, from two to six feet in thickness, abounding in roots and trunks of trees in the lower portion, and in mosses and aquatic plants in the upper and lighter-coloured portion. The trees are chiefly oaks (often of great dimensions), Scotch firs, alders, birches, hazels, and willows; and throughout are embedded hazel-nuts, seeds of various plants, and the wing-cases of insects. The forests rest for the most part on dark-blue unctuous clay, and are overlaid by from twelve to twenty feet of marine silts and sands—thus showing, *first*, that the forest-growth had been formed at a higher elevation than the present seaboard; *secondly*, that after its formation and consolidation into peat, it had been

submerged and overlaid by the sea-silts and sands; and *thirdly*, that after being covered by these silts, it had been re-elevated to its existing level. This submarine forest-growth also implies not only a greater extension of the British Islands than at present, but from the great size of its trees and the nature of the embedded insects, the existence of a somewhat warmer climate between the present day and the boulder-clay epoch. A similar horizon of submerged forest-growths has been observed on the opposite shores of the Continent, and especially along the Channel Islands, where trees, roots, branches, &c., are sometimes washed ashore after severe storms, as in the winter of 1786.

#### CHEMICAL DEPOSITS.

297. Under this head we class all deposits arising from calcareous and siliceous springs, all saline incrustations and precipitates, and all bituminous or asphaltic exudations. The most frequent deposits of a calcareous nature are calc-tuff and calc-sinter, stalagmites and stalactites, and travertine. *Calc-tuff*, as the name implies, is an open, porous, and somewhat earthy deposition of carbonate of lime from calcareous springs, and is found in considerable masses, enclosing fragments of plants, bones, land-shells, and other organisms. *Stalagmites* and *stalactites*, already noticed in par. 22, are often of considerable magnitude in limestone caverns, and are here noticed as frequently enclosing the bones and skeletons of animals found in these caverns, thus constituting *cave-earths* and *bone-breccias*. *Travertine* (a corruption of the word Tiburtinus) is another calcareous incrustation, deposited by water holding carbonate of lime in solution. It is abundantly formed by the river Anio at Tibur, near Rome; at San Vignone, in Tuscany, and in other parts of Italy. It collects with great rapidity, and becomes sufficiently hard in course of a few years to form a light durable building-stone. As with deposits from calcareous, so with deposits from siliceous springs—these forming siliceous tufa and sinter in considerable masses, as at the hot springs or *geysers* of Iceland, the Azores, New Zealand, and other volcanic regions.

298. In hot countries, incrustations of common salt, nitrates of soda and potash, and other saline compounds, are formed during the dry season in the basins of evaporated lakes, in deserted river-courses, upraised or ancient sea-levels, and in

shallow creeks of existing seas. These incrustations go on from year to year, and in course of time acquire considerable thickness, or are overlaid by sedimentary matter, and there exhibit alternations like the older formations. Such deposits are common in the sandy tracts of Africa, in the river-plains and old sea-reaches on the upheaved Pacific coasts of South America, along the coasts of India, and in the salt lakes of Central Asia. With respect to springs and exudations of petroleum, asphalt, and the like, it may be remarked that they are too limited and scanty to produce any sensible effect on the bulk of the rocky crust, and are principally of geological importance, as throwing light on analogous products of earlier date.

## ORGANIC ACCUMULATIONS.

299. Organic accumulations consist either of vegetable or of animal remains, or of an intimate admixture of both. The most important of those resulting from vegetable growth are peat-mosses, jungle-swamps, drift-rafts, and submerged forests. *Peat*, which is a product of cold or coldly-temperate regions, arises from the annual growth and decay of marsh-plants—reeds, rushes, equisetums, grasses, sphagnum, and the like, being the chief contributors to the mass, which in process of time becomes crowned and augmented by the presence of heath and other shrubby vegetation. It occupies considerable areas in Scotland and England, though rapidly disappearing before drainage and the plough; but it still covers wide areas in Ireland. It is found largely in the Netherlands, in Russia and Finland, in Siberia, Canada, and British North America, and in insular positions, as Shetland, Orkney, and the Falkland Islands. It occurs in all stages of consolidation, from the loose fibrous turf of the present generation to the compact lignite-looking peat formed thousands of years ago. Besides the peculiar plants which constitute the mass, peat-mosses contain trunks of oak, pines, alders, birches, hazels, and other trees, apparently the wrecks of forests entangled and destroyed by their growth, prostrated by storms, or felled by the hand of man. Bones and antlers of the Irish deer, elk, great red-deer, and other animals, are found in most of our British mosses, with occasional remains of human art, as tree-canoes, stone axes, querns, and coins; and not unfrequently the skeleton of man himself. As with peat-mosses in temperate latitudes, so with the jungle-growth of tropical

deltas, as those of the Niger, Ganges, and Amazon ; so with the *sudd* or matted grass-growths of the Nile and other waters of equatorial Africa ; so with the cypress-swamps (the "Great Dismal," for instance) of the United States ; and so also with the pine-rafts and vegetable debris borne down by such rivers as the Mississippi, and entombed amid the silt of their estuaries. All are adding to the solid structure of the globe, and forming beds, small it may be in comparison, but still analogous to the lignites of the Tertiary, and the coals of the Oolitic and Carboniferous eras.

300. Accumulations resulting from animal agency are universal and varied ; but those of any appreciable magnitude are chiefly coral-reefs, shell-beds, serpula-reefs, bone-shoals, and foraminiferal accumulations. The nature and growth of the coral zoophyte has been already alluded to, and we need here only observe the extent of its distribution in the Pacific, Indian, and Southern Oceans. Viewing a *coral-reef* as essentially composed of coral structure, with intermixtures of drift-coral, shells, sand, and other marine debris, we find such masses studding the Pacific on both sides of the equator, to the thirtieth degree of latitude ; abounding in the southern part of the Indian Ocean ; trending for hundreds of miles along the north-east coast of Australia ; and occurring in minor and scattered patches in the Persian, Arabian, Red, and Mediterranean Seas. In the Pacific, coral-reefs are found forming low circular islands (*atolls*), fringing islands of igneous origin (*barrier-reefs*), crowning others already upheaved (*coral ledges*), or stretching away in long surf-beaten ridges (the true *reef*) of many leagues in length, and from twenty to more than one hundred feet in thickness. Regarding them as mainly composed of coral, and knowing that the zoophytes can only add a few inches to the general structure during a century, many of these reefs must have been commenced before the dawn of the present epoch ; and looking upon them as consisting essentially of carbonate of lime, we have calcareous accumulations rivalling in magnitude the limestones of the older formations.

301. *Shell-beds*, like those formed by oysters, cockles, mussels, and other gregarious molluscs, are found in the seas and estuaries of every region, often spread over areas of considerable extent, and several feet in thickness. Dead shells, like the pearl-oyster of the Indian seas, for example, are also accumulated on certain coasts in vast quantities ; and shell-sand, entirely composed of comminuted shells, is drifted for

leagues along the shores of every existing sea. In fact, when we consider the myriads of testacea (Lat. *testa*, a shell) that throng the waters of the ocean, the rapidity with which they propagate their kind, and the indestructible nature of their shells, we are compelled to admit their accumulations to a place in the present epoch, as important as that which they held in any of the earlier eras. In treating of the Chalk and Tertiary strata, we saw what an important part had been played in the formation of certain beds by infusorial organisms and minute foraminifera; and so far as the researches of microscopists have gone, it would appear that the same minute agencies are still at work in the silt of our lakes and estuaries, and in the depths of our seas. What the eye regards as mere mud and clay, is found, under the lenses of the microscope, to consist of countless myriads of the siliceous shields of diatoms, or the calcareous shells of foraminifera—a discovery whose limits will be further extended as the microscope becomes, as it soon must be, the inseparable companion of the geological inquirer.

302. Although coral-reefs, shell-beds, and microzoal growths are the only accumulations of any magnitude arising from animal agency, yet what are usually termed *ossiferous gravels* (*os*, a bone, and *fero*, I yield), *ossiferous caverns*, *osseous breccia*, or *ossite* and *shell-mounds*, are too important in a palæontological point of view to be passed over without some notice, however cursory. River sands and gravels containing masses of drift-bones, such as the tusks and grinders of the mammoth



Fig. 157.—Whitsunday Island, or Atoll.

and elephants, the bones and teeth of the rhinoceros, hippopotamus, horse, bear, &c., and the horns and bones of the elk, stag, and wild ox, are common in the valleys of Britain, in

the river-plains of North America, and in the gravel-cliffs of Siberia and the polar seas. In South America they contain abundant remains of the gigantic ancestors of the peculiar fauna of that continent. We have the *Megatherium*, or colossal Sloth; the *Glyptodon*, or giant Armadillo; and many

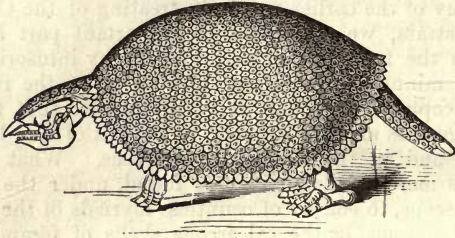


Fig. 158.—*Glyptodon clavipes*. From the Post-Tertiary of South America.

others. Caverns occurring in the limestones of England, France, Belgium, Germany, Italy, North and South America, and Australia, are often replete with bones preserved in stalagmitic incrustations, or in calcareous mud; and masses of drifted bones (osseous breccia, or ossite) occur in rents and fissures, or in small islands (upheaved shoals) like Sombrero in the West Indies, cemented together, and petrified by calcareous tufa. In this curious series of accumulations are found the relics of the *Mastodons* of North America, the mammoths of Siberia, the *Dinornis* or gigantic ostrich-like bird of New Zealand, the elephants and elks of our own valleys, and the remarkable heterogeneous accumulations of elephant, hippopotamus, horse, bear, hyæna, deer, ox, stag, and other bones found in the British limestone caverns of Yorkshire, Derbyshire, Somerset, and Devonshire. Most of these remains belong to animals now extinct in the countries where they occur, and point to a period during, or immediately succeeding, the Glacial or "Boulder-drift." Occasionally, as in Britain (Brixham), Belgium, France, Dordogne, &c., and along the shores of the Mediterranean, human bones, the embers of fires, stone implements, and other traces of savage life, are found in these caverns; and though in some instances man has evidently become the tenant long after the other bones were embedded, yet in many others the remains have accumulated simultaneously, thus showing that our race was coeval with the mastodon in America, with the elephant in

Britain, and with the herds of mammoths that browsed on the ancient river-plains of Siberia.

303. Among organic accumulations which have received

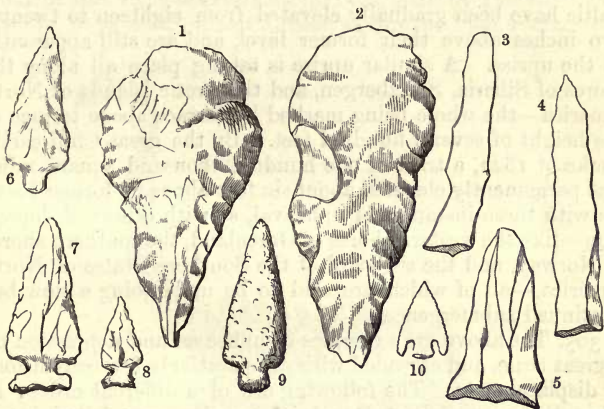


Fig. 159.—Early Stone Implements.  
*Palaeolithic*—1, 2, *From Valley of Somme*; 3, 4, 5, *England*.  
*Neolithic*—6, 7, 8, *Canada*; 9, 10, *Scandinavia*.

much attention from antiquarians and geologists, we may notice the *shell-mounds* of Britain, the *Kjökken-mödding* or “kitchen-middings” of Denmark, and the *Sambaquis* of America. These mounds, which vary from 3 to 10 feet high, and from 100 to 1000 feet in their longest diameter, consist chiefly of the castaway shells of the oyster, cockle, periwinkle, and other edible kinds of shell-fish. They are ascribed by archæologists to an early Neolithic people unacquainted with the use of metal, as all the implements found in them are of stone, horn, bone, or wood, with fragments of rude pottery and traces of wood-fires. All the bones yet found are those of wild animals, with the exception, perhaps, of the dog, which seems to have been domesticated.

#### EFFECTS OF SUBTERRANEAN AGENCIES. IGNEOUS OR VOLCANIC ACCUMULATIONS, &C.

304. The effects of subterranean action, whether manifesting itself in quiet upheavals, in earthquakes, or in volcanoes, are of prime importance; and though in certain areas, the present

epoch, as compared with some of the past, be one of rest and tranquillity, yet wide regions of the globe bear witness to extensive modifications even within the history of man. Since the commencement of the present century, the N. shores of the Baltic have been gradually elevated from eighteen to twenty-two inches above their former level, and are still apparently on the uprise. A similar uprise is taking place all along the shores of Siberia, Spitzbergen, and the Arctic islands of North America—the whole being marked by terrace above terrace to the height of several hundred feet. By the great Chili earthquake of 1822, a tract of one hundred thousand square miles was permanently elevated about six feet above its former level. As with these instances of upheaval, so with others of depression—like the western shores of Greenland, the southern shores of Norway, and the seaboard of the Southern States of North America,—all of which are said to be undergoing a slow but continued submergence.

305. The above are examples of upheaval and depression on a great scale, and attended with comparatively few convulsions or displacements. The following are of a different order: In 1692, the town of Port Royal, in Jamaica, was visited by an earthquake, when the whole island was frightfully convulsed, and about a thousand acres in the vicinity of the town submerged to the depth of fifty feet, burying the inhabitants, their houses, and the shipping in the harbour. The disasters of the great Lisbon earthquake in 1755, when the greater part of that city was destroyed, and sixty thousand persons perished in the course of a few minutes, have been repeatedly recited; as have also those of Calabria, which lasted nearly four years—from 1783 to the end of 1786—producing fissures, ravines, landslips, falls of the sea-cliff, new lakes, and other changes; while the convulsions and disasters which took place in the West Indies, along the Pacific coast of South America, in the Sandwich Islands, in Italy, in Spain, and in the East Indies, must be fresh in the memory of every newspaper reader.

306. The eruptions of Etna and Vesuvius are matters of everyday notoriety; the burying of Herculaneum and Pompeii is a subject of high historic interest. In 1783, the discharges of the Skaptar Jökul, in Iceland, continued for nearly three months, producing the most disastrous effects, as well as most extensive geological changes on the face of the island. Whether as lava, pumice, scoræ, dust, hot mud, or ashes, volcanic products, both on land and under the ocean, are materially adding to the structure of the rocky crust. Nor is it to the

mere accumulation of igneous rock-matter in certain localities that the student must look for the chief results of volcanic effort. As in former epochs, so in the present we have lines and axes of regional elevation; and chains of hills, like those pointed out by Von Tschudi in Peru, and by Darwin in the Pacific, have been formed almost within the human era.

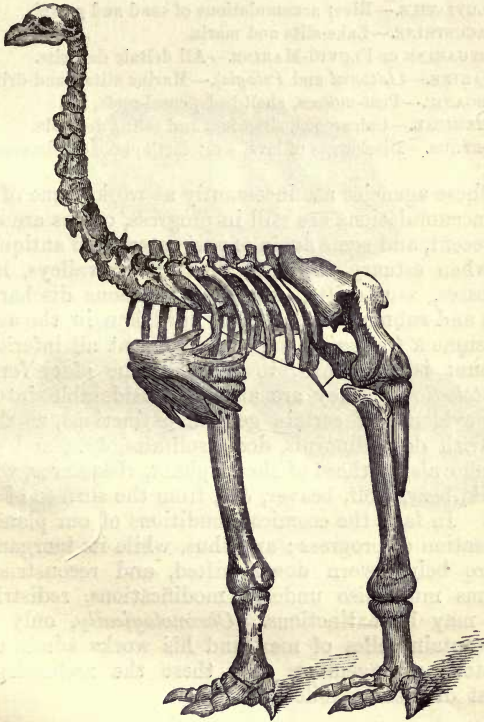


Fig. 160.—*Skeleton of Dinornis elephantopus, greatly reduced. Post-Pliocene, New Zealand. (After Owen.)*

RECAPITULATION.

307. In the preceding chapter we have briefly indicated the nature and extent of the various accumulations that have taken place since the close of the Boulder-drift; in other words,

since sea and land acquired the outlines of their present configuration, and were peopled by existing species. These accumulations we have classed under the head POST-GLACIAL, QUATERNARY, RECENT or SUPERFICIAL, and subdivided into the following groups, according to the agents chiefly concerned in their aggregation:—

FLUVIATILE.—River accumulations of sand and gravel.

LACUSTRINE.—Lake-silts and marls.

ESTUARINE or FLUVIO-MARINE.—All deltaic deposits.

MARINE.—(*Littoral* and *Pelagic*).—Marine silts, sand-drifts, &c.

ORGANIC.—Peat-mosses, shell-beds, coral-reefs, &c.

CHEMICAL.—Calcareous, siliceous, and saline deposits.

IGNEOUS.—Discharges of lava, &c.; earthquake displacements.

As all these agencies are incessantly at work, some of the preceding accumulations are still in progress, others are comparatively recent, and some again of vast extent and antiquity. Indeed, when estuary deposits, alluvium in valleys, lake-silts, peat-mosses, sand-drifts, coral-reefs, igneous discharges, upheavals and submergence of land, are taken in the aggregate, they assume a *Geological* importance not at all inferior, as far as amount is concerned, to those of the older formations. *Palæontologically*, they are also of considerable interest, affording evidence of certain general extinctions, as the mammoth, Irish deer, dinornis, dodo, solitaire, &c.; and of many local removals, as those of the elephant, rhinoceros, wild boar, urus, elk, bear, wolf, beaver, &c., from the surface of our own islands. In fact, the cosmical conditions of our planet forbid any cessation of progress; and thus, while its inorganic materials are being worn down, sifted, and reconstructed, its organisms must also undergo modifications, redistributions, and it may be extinctions. *Chronologically*, only deposits which contain relics of man and his works admit of fairly satisfactory arrangement, and these the archæologist and geologist divides as follows:—

1. HISTORIC.

- |                  |   |                                  |
|------------------|---|----------------------------------|
| 2. PRE-HISTORIC. | { | 3. Bronze and Iron age.          |
|                  |   | 2. Neolithic or New Stone age.   |
|                  |   | 1. Palæolithic or Old Stone age. |

The palæolithic age yields us the first traces of man and his handiwork; and in the subsequent deposits, we find the evidences of his gradual advance in intelligence and civilisation up to the period when he makes his appearance upon the

pages of history ; and here the geologist resigns the task of describing his progress, and that of the world he inhabits, and the creatures that share it with him, to the historian, the geographer, and the biologist.

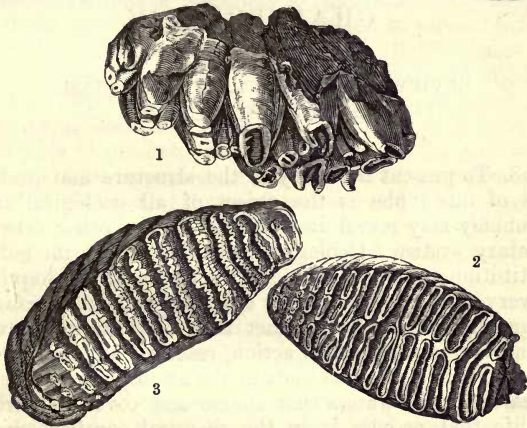


Fig. 161.—1, *Grinder of Mastodon* ; 2, of *Mammoth* ; 3, of *Asiatic Elephant*.

## CHAPTER XXIV.

REVIEW OF THE STRATIFIED SYSTEMS.—  
GENERAL DEDUCTIONS.

308. To present a history of the structure and past conditions of our globe is the object of all geological inquiry. Astronomy may reveal its relations to the other orbs of the planetary system; Geology alone can unfold its individual constitution and structure. At the outset of his inquiry—on the very surface of the rocky crust he is about to examine—the geologist is met by the fact that everything beneath and around him is in ceaseless action, reaction, and change. The causes of this change he finds in the atmosphere that envelops the earth, in the waters that course and cover its surface, in the life that peoples it, in the chemical constitution of the substances of which it is composed, and in the forces that act within its interior. These are ever and everywhere active: here wasting and degrading, there accumulating and reconstructing; here submerging the habitable dry land beneath the ocean, there upheaving the sea-bottom to form new islands and continents; and anon preserving in the re-formed material the remains of plants and animals as evidences of the world's geographical conditions at the time of their entombment. As at the present moment, so in all time past, similar operations must have been going forward, and the results are manifested in the rock-formations of the solid crust which it is the province of Geology to investigate.

309. In this rocky crust we find sandstones that must have formerly spread out as sandy shores; conglomerates that formed pebbly beaches; shales that were the muds and clays

of former lakes and estuaries ; limestones that once were living coral-reefs ; and coal-beds composed of the remains of a bygone vegetation. Here, also, we discover embedded corals and shells and fishes that must have lived in the ocean ; reptiles that thronged shallow bays and estuaries ; huge mammals that browsed on river-plains ; and plants, some that flourished in the swampy jungle, and others that reared their trunks in the tropical forest. Of all this there is the clearest and most abundant evidence ; and by comparing and arranging, by tracing back from the plants and animals entombed in the accumulations of yesterday to the fossils in the deepest-seated strata, geologists have been enabled to present a fairly vivid outline of the world's history,—of all its phases and conditions from the earliest time we have traces of organisation and life, up to the existing order of things, of which Man is the natural head and ornament. Geology, it is true, will never be able to present a series of pictures of the past conditions of the globe so perfect in their details as those geography can draw of its existing terraqueous aspects ; but the science has already sketched a wonderful outline of world-history, and every discovery and well-founded deduction contributes to the completeness of the sketch.

310. The exponents of this history, we have said, are the rocky strata of the globe ; and these, after diligent research in many and distant regions, have been arranged into systems and groups, according to their order of superposition or relative age—each set being spread over certain areas, marked by some peculiarity of mineral composition, and characterised by the remains of certain plants and animals not found in any other series of strata. In fine, each group or formation represents a portion of world-history—the only record of the conditions, the events, and the life of that period being in the nature of the strata themselves, or in the plants and animals they entomb. Tabulated in chronological order, these systems and groups present the following succession : and could we map out their respective areas in the same manner as we do the existing sea and land, and restore the forms of their fossil plants and animals, Historical Geology would in great part have accomplished its task, and have done for the past phases of the globe what geography and natural history are doing for its present features :—

## STRATIFIED ROCKS OF EUROPE.

	SERIES.		SYSTEMS.	PERIODS.	LIFE TYPE.
QUATER-NARY.	{ Recent and Pre-historic accumulations. Pleistocene or Glacial.		POST-TERTIARY.		ANTHROPOZOIC.
TERTIARY.	{ Pliocene or Crag. Miocene. Oligocene. Eocene.	{ UPPER. LOWER	TERTIARY.		CENOZOIC.
SECONDARY.	{ Maestricht or Danian. Upper White Chalk. Lower White Chalk. Upper Greensand. Gault. Lower Greensand. Wealden and Neocomian. Upper Oolite or Portland Series.	{ UPPER. LOWER.	CRETACEOUS.		NEOZOIC.
	{ Middle or Oxfordian. Lower or Bathonian. Upper Lias. Middle Lias or Marlstone. Lower Lias.	{ OOLITE. LIAS.	JURASSIC.		
	{ Rhætic or Penarth Series. Upper Triassic or Keuper. Middle or Muschelkalk. Lower or Bunter.	{ RHÆTIC. TRIASSIC.		MESOZOIC.	
PRIMARY.	{ Magnesian Limestone. Red Sandstones. Coal-Measures. Millstone Grit. Carboniferous Limestone Series.		PERMIAN OR DYASSIC.		PALEOZOIC.
	{ Upper Devonian. Middle Devonian. Lower Devonian.	{ Upper and Lower Old Red Sandstone.	DEVONIAN.		
	{ Upper Silurian or Ludlow. Middle or Wenlock. Lower or Llandovery.		SILURIAN.		
	{ Upper Ordovician or Caradoc. Middle or Llandeilo. Lower or Arenig.		ORDOVICIAN.		
	{ Upper Tremadoc Slates. Lingula Flags. Lower Menevian Group. Harlech Group.		CAMBRIAN.		
ARCHÆAN.	{ Stratified—Pebidian and Uriconian. Schistose—Hebridean and Laurentian.		{ HURONIAN. LAURENTIAN.		EOZOIC.

## STRATIFIED ROCKS OF NORTH AMERICA.

Cave Deposits, Blown Sands, Raised Beaches.	}	RECENT.	}	POST-TERTIARY.				
Alluvium of Modern Rivers, Artificial Mounds, &c.								
Champlain Series, River Terraces, <i>Saxicava</i> Sands.	}	POST-GLACIAL.						
Boulder Clays, Moraines, and Gravels, &c.								
Sumter Group of Carolina: <i>Equus</i> and <i>Protohippus</i> Beds of Upper Missouri.	}	PLIOCENE.	}	TERTIARY.				
Yorktown Beds of Eastern States, White River Group of Rocky Mountains areas, with <i>Miohippus</i> , &c.								
Alabama Series: Winton, Bridges, Green River, and Wasatch Groups of the Rocky Mountains, with <i>Eohippus</i> .	}	Eocene.						
Laramie or Lignitic Series: Fox Hills, Colorado and Dakota Groups of the Western States.		}	MESOZOIC.					
Atlantosaurus Beds of Colorado, &c.	}					JURASSIC.		
Connecticut River Beds: <i>Dromatherium</i> Beds of North Carolina; <i>Halobia</i> Series of Elk Mountains and the Pacific Slope.								
Sandstones and Marls of Kansas.	}	PERMIAN.	}	DEUTEROZOIC.				
Coal-Measures and Millstone Grit of Pennsylvania Central Basin, and Nova Scotia, &c.								
Sub-Carboniferous Series of Limestones and Shales.	}	CARBONIFEROUS.						
Catskill, Chemung, Portage, and Corniferous Series of the Mississippi and St Lawrence Basins.		}	DEVONIAN.					
Lower Helderberg Series: Salina Formation, Niagara and Clinton Beds; Medina and Oneida Rocks.	}					SILURIAN.		
Hudson River (Lorraine) and Utica Series.								
Marsouin River Beds, Trenton Limestone Series.	}	ORDOVICIAN.	}					
Chazy Limestone, and <i>Phyllograptus</i> Rocks of Point Levis.								
Calcareous Limestones of Canada and Newfoundland. <i>Dictyonema</i> Beds of Cape Breton and Gaspé.	}	CAMBRIAN.						
Potsdam Sandstone of Canada, &c.; Acadian Series of New Brunswick.								
<i>Olenellus</i> Beds of Vermont and Rocky Mountains.	}							

Keweenaw and Huronian Series of Lakes Superior and Huron.	} HURONIAN ?	} EOZOIC.
Eozoonal Limestone and Gneissic Series of Canada, and the Adiron- dack Mountains.		

311. Such are the stratified systems composing the crust of the globe, and such the life-types of vegetable and animal existences that have successively peopled its surface—the pages and pictures, as it were, of the onward and upward history of our planet. In these we find a long gradation of change and progress—not progress from imperfection to perfection, but from humbler to more highly organised forms. From the lowly sea-weeds of the Silurian strata and marsh-plants of the Old Red sandstone, we rise to the prolific reeds, tree-ferns, and gigantic lycopods of the Coal-Measures; from these to the conifers, cycads, and pines of the Oolite; and from these again to the exogens or true timber-trees of the present era. So also in the animal kingdom; the graptolites and the trilobites of the Silurian seas are succeeded by the eurypterites and bone-clad fishes of the Old Red sandstones; these by the sauroid fishes of the Coal-Measures; the sauroid fishes by the gigantic saurians and reptiles of the Oolite; the reptiles of the Oolite by the huge mammalia of the Tertiary epoch; and these in time give place to present species, with Man as the crowning form of created existence.

312. We have seen that certain agents are ceaselessly modifying the superficial configuration of the earth, and giving rise to new conditions; and as plants and animals are influenced in their forms and distributions by external causes, these new conditions must be accompanied by new phases and arrangements of vitality. So it has been in the past, as we see graven on the rocky records of geology; so it is now; and so, we infer, it will ever continue to be, under the ceaseless superintendence of an all-wise and beneficent Creator. To discover the facts of this long gradation of change and progress, and to combine the whole into a connected and intelligible history of our planet, is the aim of all geological inquiry—an aim not the less interesting or important that it bears directly on the procuring of those minerals and metals which add so greatly to the comforts and luxuries of life, and contribute so materially to human progress and civilisation. Combining its theoretical interests with its high practical value—the complexity and nicety of its problems as an intellectual exercise, with the substantial wealth of its discover-

ies—the new light it throws on the past duration of our planet and the wonderful variety of its past life, with the certainty it confers on our industrial researches and operations—Geology becomes one of the most important of modern sciences, deserving, indeed, the study of every cultivated mind, and the encouragement of every enlightened government.



## GLOSSARIAL INDEX.

\* \* \* *The figures refer to the sections of the text in which the particular term or subject occurs.*

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- Trilobites (Gr. *treis*, three; *lobos*), 175, 176, 187, 195.
- Tuff or Tufa (Ital. *tufa*; Gr. *tophos*), originally applied to any light porous lava or pumice, but now to all open porous rocks; hence trap-tuff or tuff, stratified volcanic dust; calc-tuff or tufa, calcareous sinter.
- Turrilite (Lat. *turris*, a tower), a spirally-coiled chambered shell or cephalopod, belonging to the chalk formation, 264.
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Whin or whinstone, a local designation  
for any hard rock, as basalt, &c.

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25.

Zechstein (mine-stone), a term applied  
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containing the *kupfer-schiefer* or cop-  
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